A Coral Reef Symposium on Practical, Reliable, Low Cost Monitoring Methods for Assessing the Biota and Habitat Conditions of Coral Reefs

January 26-27, 1995
Annapolis, Maryland

Co-Sponsored by
the Office of Water, U.S. Environmental Protection Agency and the Office of Ocean and Coastal Resource Management, National Oceanic and Atmospheric Administration, with additional support from the U.S. Man and the Biosphere Program

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Please cite as: Crosby, M.P., G.R. Gibson, and K.W. Potts (eds). 1996. *A Coral Reef Symposium on Practical, Reliable, Low Cost Monitoring Methods for Assessing the Biota and Habitat Conditions of Coral Reefs, January 26-27, 1995.* Office of Ocean and Coastal Resource Management, National Oceanic and Atmospheric Administration, Silver Spring, MD.

CONTENTS

A CORAL REEF SYMPOSIUM ON PRACTICAL, RELIABLE, LOW COST MONITORING METHODS FOR ASSESSING THE BIOTA AND HABITAT CONDITIONS OF CORAL REEFS

Cosponsored by U.S. EPA and NOAA

January 26-27, 1995
U.S. EPA Region III Conference Room
201 Defense Highway, Suite 200
Annapolis, Maryland

AGENDA

Thursday, January 26

10 a.m.	Opening Remarks and Introductions
10:30 a.m.	Paul Jokiel, Hawaii
11 a.m.	Ernst Reese, Hawaii
11:30 a.m.	Robert Richmond, Guam
noon	Lunch
1:30 p.m.	Jim Bohnsack, Florida
2 p.m.	Pamela Hallock-Muller, Florida
2:30 p.m.	Walter Jaap, Florida
3 p.m.	Break
3:30 p.m.	Summary Comments by Presenters and Open Discussion
4:30 p.m.	Separate Concurrent Informal Break-out Sessions: 1. "Low tech" volunteer-based methodologies for coral reef surveys. 2. Investigations of nutrient (sewage effluent) impacts on coral reefs.
6:30 p.m.	Adjourn
7 p.m.	Dinner and Continued Discussions at a Local Restaurant

Friday, January 27

8:45 a.m.	Reconvene
9 a.m.	Laurie Richardson, Florida
9:30 a.m.	Alina Szmant, Florida
10 a.m.	George Sedberry, South Carolina
10:30 a.m.	Break
11 a.m.	Morning Session (continued)
noon	Lunch
1:30 p.m.	Caroline Rogers, U.S. Virgin Islands
2 p.m.	Jeremy Woodley, West Indies
2:30 p.m.	Summary Comments by Presenters and Open Discussion
4 p.m.	Adjourn

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INTRODUCTION TO THE SYMPOSIUM

(Portions of this section are derived from a recent publication — "Coral Reefs and Biodiversity: A Critical and Threatened Relationship" by J.E. Maragos, M.P. Crosby, and J. McManus, Oceanography, in press.)

Most of what we have learned about coral reefs has been gathered by scientists during the past 150 years, beginning with Charles Darwin and James D. Dana in the mid-19th century (Darwin 1842, Dana, 1872). Darwin first postulated that the subsidence of volcanic islands can result in the evolution of fringing reefs to barrier reefs and atolls. Dana, as geologist aboard the U.S. Exploring Expedition (1838-1842) which circumnavigated the globe, was able to publish the first definitive global distribution of coral reefs. He also addressed some of the major factors — the need for warm sea water temperatures (generally greater than 21° C) and light — that contribute to vigorous reef growth, and described more species of corals than any other scientist before or afterwards. Other pioneering reef scientists through the early twentieth century include Stanley Gardiner, Alexander Agassiz, Alfred Mayor, Thomas Vaughan, Maurice Yonge, and Cyril Crossland. Important earlier expeditions and laboratories focusing on coral reefs research occurred on Bermuda, the Great Barrier Reef, the Dry Tortugas and in Palau. The more recent use of drilling equipment, submersibles, scuba equipment, modern laboratory equipment, and other technological innovations ushered in the era of modern coral reef research and inquiry, beginning with works of John Wells, Joshua Tracey, and Harry Ladd, with co-workers on several atolls in the Marshall Islands beginning in the 1940's and with Thomas Goreau, in Jamaica, beginning in the late 1950's. However, the highly technical, sophisticated and often expensive methods that modern science employs to assess the status and trends of coral reef habitats can limit the involvement of volunteers and local people who lack "classical" scientific training or significant funding resources.

Coral reef ecosystems are an important resource not only in terms of their biological diversity and productivity, but also as the foundations of coastal protection, tourism, subsistence economies, and in many areas as focal points for cultural and community heritage. On the Great Barrier Reef, the visitor and resort industries annually gross over a billion dollars a year in revenues. Using the United States as an example:

- In all U.S. coral reef areas, reefs are the basis for most tourism and most tourism development, accounting for billions of dollars in construction and sales annually. The Florida Keys reef tract is a primary attraction which draws an estimated 2 million tourists to the Keys, with a direct revenue impact approaching $800 million (1990 figures);

- In American Samoa, coral reefs play a central role in all aspects of traditional culture, from land tenure to diet. Reefs account for more than 50% of all fish caught locally; and
- For Guam and the Northern Mariana Islands, which lie in the track of "Typhoon Alley," reefs provide protection from extraordinary ocean action which would otherwise devastate whole communities and result in the expenditure of tens of billions of dollars in federal disaster assistance.

For over millions of years coral reefs have shown remarkable power of resiliency and adaptations to environmental changes. However, the ability of coral reef ecosystems to exist in balanced harmony with other naturally occurring competing or limiting physical-chemical, and biological agents has been severely challenged in the last several decades by the dramatically increased negative and synergistic impacts from poorly managed anthropogenic activities. A variety of natural factors may prevent net reef growth, especially prolonged periods of adverse conditions, such as cold and extreme high temperatures, storm activity, earthquakes, lava flows or excessive sea level rise or fall such as the sea level functions occurring during the glacial and interglacial ages. The advent of anthropogenic stresses or threats to coral reefs can also disrupt coral reef survival and growth, resulting in net erosion and deterioration of reef structures. The synergistic effects of natural and anthropogenic disturbances may exacerbate adverse effects to coral reefs.

The major documented impacts to coral reefs occur near urban areas, and the reasons are simple. Lands are cleared for housing, agriculture, livestock grazing, and other development, thereby eroding soils and resulting in sedimentation and runoff to coral reefs. Coastal construction for harbors, shore protection, causeways, channels, airfields, roads, and building materials are also located near urban centers. Sewage and industrial discharges are concentrated, and edible reef species are more heavily harvested and depleted. Huge tracts of mangroves have been converted to shrimp ponds. Popular recreational reef areas are trampled by waders, smashed by anchors, and harvested by shell and coral collectors. It is no surprise therefore that most reef destruction and damage is chronic and occurs in such centers. Furthermore, most research facilities, colleges, and universities in the tropics are also located in population centers. Hence, the damage and destruction are also documented primarily by scientists living in such centers, and their research is supported by the political will and financial support that are also more concentrated in these locations. Nonpoint source pollution, eutrophication, the introduction of alien species from aquaculture schemes and oil spills and ship groundings also occur more often near population centers.

Coral reefs are also being degraded at an alarming rate in more remote areas, although documentation and evidence is less extensive. Remote reefs are being preferentially degraded by illegal or destructive fishing and harvesting practices. Remote atolls and submerged shallow reefs attract more than their share of shipwrecks, oil spills, and groundings; many are tiny and nearly invisible beyond a few kilometers, and navigation charts in remote areas are not always accurate. The frequent occurrence of coral bleaching on many reefs in recent years and increased greenhouse gas emissions are leading many scientists to believe that global climate change may lead to further coastal degradation and damage to coral reefs from flooding, sea level rise, and increased incidence and intensity of storms. While linking a "greenhouse" effect to coral bleaching is controversial, recent remote sensing studies of sea surface temperatures by the National Oceanic and Atmospheric Administration (A. Strong, pers. com.) and others (see *Science* 270:919) seem to demonstrate correlations between elevated water temperature and recent bleaching events in Belize.

The United States and Local Coral Reef Initiatives

An outgrowth of the International Coral Reef Initiative — the ICRI is a partnership among nations and organizations seeking to implement chapter 17 of the UNCED's Agenda 21 and other international conventions and agreements for the benefit of coral reefs and related ecosystems — is the development of national coral reef initiatives. The United States has developed an interagency CRI to create the base for a combined domestic and international effort aimed at the conservation and effective management of coral reef ecosystems (Crosby et al., 1995, Crosby and Maragos, 1995). The U.S. CRI is building on existing federal, state, territorial, commonwealth, and local partnerships through communication with relevant stake holders at all levels. Mechanisms for ongoing consultation among stakeholders have been initiated and are being expanded to take into account local needs, priorities, and opportunities. Under the U.S. CRI, the National Oceanic and Atmospheric Administration (NOAA) and the Environmental Protection Agency (EPA) are working in partnership with other agencies and organizations at the federal, state, territory, and commonwealth level, seeking to integrate their operational management and assessment activities in an ecosystem-wide approach, increase monitoring, conduct assessments to provide better information for decision makers, provide education and outreach to increase public understanding, and undertake a more proactive effort to understand and maintain the biodiversity of coral reef ecosystems.

Overview of the NOAA/EPA Symposium

Participants in this NOAA/EPA Coral Reef Symposium included specialists with expertise in the study of both Pacific and Caribbean coral reefs who were requested to discuss what they considered to be the most promising "low-tech" approaches to coral reef survey and biological assessment. The overall group was purposefully kept small to preserve the open discussion intent of the symposium. However the makeup of the group included representatives from academia, as well as state and federal agencies, and was able to provide a broad representation of the state of coral reef science. The symposium was designed to:

- Provide input for biological criteria development and subsequent management and protection efforts by NOAA, EPA and other involved federal and state organizations, and
- Identify "low-tech" approaches that have potential for local-level volunteer efforts aimed at monitoring and assessing coral reefs

EPA and NOAA are also interested in reviewing concepts and approaches that may form the basis of a technical guidance manual for resource managers involved in monitoring and assessing coral reefs. It is important to standardize approaches as much as possible, always recognizing the site-specific nature of the project and the diversity of coral reefs worldwide. Such a technical guidance manual could be used by coastal state resource agencies to develop biocriteria for coral reef ecosystems — similar to the biocriteria programs EPA already has for surface water resources, streams and small rivers, wetlands, lakes and coastal estuaries. It is anticipated that this dialog will be useful to the research community and help EPA determine if it should proceed with a guidance manual for coastal reef ecology (it has received requests for such a document from Puerto Rico and Hawaii). This symposium provided a forum for discussion of preferred and favorite techniques, their practicality, cost-effectiveness and degree of complexity. Scientifically robust techniques are needed in order to monitor and manage coral reef ecosystems, particularly in the current potentially litigious atmosphere.

The use of a consistent and robust biological survey protocol, whether from volunteers or professional technicians, to provide scientifically valid information and long-term assessments of the condition of a nationally coordinated set of "index" sites (to include both "natural" reference or control sites as well as "high impact" sites) is critically important for the management of coral reef ecosystems for long-term sustainable use and conservation. It is expected that this Symposium will directly benefit the U.S. and local-level CRIs by providing suggestions on promising low cost/"low-tech" monitoring and assessment approaches to U.S. State, Territory and Commonwealth Coastal Zone Management Programs that will assist in their efforts to promote long-term sustainable use and conservation of their coral reef resources.

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PRESENTATION AND DISCUSSION SUMMARARIES

Assessment and Monitoring of U.S. Coral Reefs in Hawaii and the Central Pacific

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Geographic Extent of U.S. Coral Reefs in the Central Pacific

A general description, compilation of reef resources and environmental assessment for all U.S. reefs in the central Pacific has been presented by Wells and Jenkins (1988). The Hawaiian Archipelago is the longest and most isolated chain of islands in the world, extending over a distance of nearly 2500 km from the island of Hawaii in the south-east to Kure Atoll in the north-west Pacific Ocean. Environmental management of reefs in the archipelago falls under various Federal, State and county jurisdictions. Central Pacific U.S. reefs with status of National Wildlife Refuge include Howland Island, Jarvis Island, Baker Island and Johnston Island. Palmyra Atoll is a privately owned sovereign territory of the U.S. North of Palmyra is Kingman Reef which is claimed by the U.S. Wake Atoll an incorporated U.S. territory administered by the U.S. Air Force.

Environmental Status of Central Pacific Islands

Overall, U.S. coral reefs of the Central Pacific are among the least threatened by anthropogenic stressors (Wells and Jenkins, 1988; Wilkerson, 1994; Ginsburg and Glynn, 1994). The general health of these reefs can be attributed to a number of factors. Human population is still relatively low compared to developing nations. The State of Hawaii has a vested interest in health of reefs due to the tourist-based economy, while most of the other U.S. reefs have been given refuge status. Hawaii and the Central Pacific reefs lie far from the influence of large continents. Deep water, high wave energy and ocean currents sweep pollutants away from the reefs. Nevertheless, many localized problems of great concern continue to emerge. These are related to continued human population growth, urbanization and development. Ocean outfalls, urbanization, and massive coastal recreational development (hotels, golf courses) are presently focal points in Hawaii. The one major environmental concern on the other U.S. Central Pacific reefs has been the construction and operation of the Johnston Atoll Chemical Agent Disposal System (JACADS).

Characteristics of Central Pacific Reefs in Reference to Assessment and Monitoring

Isolation of reefs has led to an attenuated fauna compared to the western Pacific. Coral diversity and reef development along exposed coastlines of the high islands of Hawaii is low, being limited by storm surf (e.g., Grigg and Maragos, 1974).

These two features have a bearing on reef assessment and monitoring activities. Surveys are facilitated by the relative simplicity of the reef biota. Difficulties are presented by the geographic extent of the reefs and heavy wave action along exposed coastlines.

Assessment/Monitoring Activity to Date

Large numbers of studies in the "environmental assessment" category have been conducted in the Hawaiian Archipelago. These are of several main types: 1. coral reef ecological studies published in peer-reviewed literature, 2. theses and technical reports, 3. environmental impact assessments and 4. data taken intermittently by various agencies or consultants and filed as unpublished reports.

Long term monitoring programs for meteorological, hydrological (tide station, temp., density) and stream flow are available for many coral reef locations. Programs for monitoring of biota on coral reefs in Hawaii and the Central Pacific have been undertaken in several instances, but generally have been terminated due to lack of funding after 3 to 6 years. Long-term monitoring programs that have persisted are those driven by economics. These fall into two main areas: 1. monitoring of reef fish stocks by the State Department of Land and Natural Resources with funding from the recreational fisheries and 2. monitoring of corals and coral biota required by the Department of Health for coastal projects (e.g., Barber's Point Harbor and industrial area development, various outfalls). For example, monitoring of corals off Kahe Point, Oahu by photographic technique has been conducted annually for over a decade as a requirement for continued operation of an electrical generation station. Some unfunded studies (e.g., Hunter and Evans, 1994) have yielded good results due to the persistence of the investigators.

Attempts to continue excellent ecosystem research programs beyond normal funding cycles in this region have failed. For example, the classic studies of Smith et al. (1981) were terminated despite great effort to secure continued funding into the monitoring phase.

Case Study: Environmental Assessment of Kahoolawe Island, Hawaiian Islands

A recent assessment of the coral reefs of Kahoolawe (Jokiel et al., 1993) provides useful information on methods, cost effectiveness and practicality of standard techniques in our geographic area. Fish surveys produced important information relevant to management of for commercial and recreational fishermen, but reef corals proved to be sensitive indicator species for habitats across a wide spectrum of wave activity, storm exposure and sediment inputs. Processes in these habitats are dynamic, a snap-shot approach produced an accurate assessment of the relative importance of water motion and sedimentation. These surveys were hampered by the logistical problems associated with working on exposed coastlines at great distances from the "home base." This program secured substantial agency and volunteer support, the costs for each fish/coral/sediment transect were approximately $3,000. Most of that cost was logistic and administrative. Costs for establishing permanent transects for long-term monitoring would be substantially greater (probably $5,000 per transect) because of greatly increased diver time needed to set the markers. Subsequent resurveys would cost on the order of the original $3,000 per station.

Ask No Questions and You Will Get No Answers. *There is no such thing as a free lunch.*

Review of the reef monitoring and assessment activities in our region lead us to three conclusions:

1. Assessment and monitoring studies designed to answer a clearly stated question yield useful results. Studies that are not designed to answer specific questions usually produce "data" without any useful management or scientific outcome.

2. An extensive literature on coral reef research methods has long existed (e.g., Stoddart and Johannes, 1978). Given a clear research question, we can design a cost-effective assessment and monitoring program that will answer that question.

3. Quality research requires sufficient funding. Short-term assessment programs in our region have succeeded because they fit within normal agency funding cycles. Monitoring programs have inevitably failed due to lack of funding continuity.

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Summary of Group Discussion

Assessment and Monitoring of U.S. Coral Reefs in Hawaii and the Central Pacific

Wells and Jenkins (1988) have described the many coral reefs in the Hawaiian Archipelago — some of which have not been seen, let alone assessed or monitored. Many of the Hawaiian reefs are refuges, others are important to state tourism. Some are dumps containing old weaponry or nerve gas, and some were previously used as nuclear testing sites. Federal, state and counties share jurisdiction of the reefs, but state agencies have generally taken the financial role in their protection. The recent short-fall in the Hawaii's treasury will no doubt end this happy condition.

Central Pacific reefs are among the least threatened by human induced stresses and generally have an easy to study, simple biotic community though spread over an extensive geographic area. They are subject to deep water ocean currents and high wave activity that helps flush away pollutants, but the heavy wave activity also exposes them to danger and makes their study difficult. They are usually not located near dense urban populations, or near large land masses (as are reefs off-shore of developing countries); but they are subject to continued human population growth, urbanization and development. More important, attempts to extend data gathering expeditions are costly and not always congruent with the goals of the regulating agencies, so funding initiatives are usually not renewed after one or two years.

Graduate school theses and technical reports, peer-reviewed literature, environmental impact statements (EIS) and unpublished agency reports are among many available studies of coral reefs. Long-term programs are usually done to monitor economically important fish stocks or projects required by the Department of Health, as part of the permitting protocol for utilities, for example, to measure the effects of hot water discharges from power generation.

Reefs in the central Pacific are generally doing well. After the 1965 floods, barrier reefs recolonized nicely, but after sewage dumping in 1975, they did not rebound until the sewage discharges were diverted. This finding suggests that under pristine conditions, reefs will renew themselves once a temporary degradation is discontinued, as long as the substrate is stable. The presence of fines in dynamited areas prevents good substrate for recolonization; dredged areas do not have fines. Erosion and sedimentation can significantly impair that substrate and the potential for recovery.

In the Pacific, a complicating factor for any reef investigation is the hazard of jettisoned bombs and other wartime weapons. Explosive Ordnance Disposal (EOD) personnel are needed on all projects to disarm World War II ordnance — which may enhance the adventure but also adds to the cost of the project. To hold these costs down, volunteers are engaged in some projects, and Earth-Watch has a project on Maui, (so some volunteers not only freely assist but even pay to be included).

If coral health is your measure of success, then fish must be included in your indicator species. Indicator species must be quick to respond to water quality and other environmental changes — it will be too late to influence the populations if we simply monitor changes in the corals themselves.

Successful methodologies are driven by good experimental design: one must have a clear question to start from, otherwise data are unclear and without management outcomes. Using a grid (Fig 1.) to determine the what, who and why of your monitoring program helps keep the research question clear and unambiguous. The subsequent assessments are snap-shots of a reef's current status. Monitoring along transects, with photos, videos or other methods — and physical monitoring — should be long-term and seasonal, and should be done to measure status and management objectives relative not only to restoration where needed, but also prevention.

Environmental Impact Statements (EIS) are nearly always useless and untrustworthy because contractors often have interests in common with the developers who hire them. But note well this key point: We could remedy this defect by adopting the Australian model, which builds peer review into the system from the beginning. A contractor may have a direct relationship with developers but his or her EIS is subject to independent review by scientists who are contracted separately and paid for their reviews.

Assessment Monitoring

why?

who?

what?

how?

Figure 1. Question/answer grid the investigator should complete to help understand the investigative question and the reason for the work.

We may also want to suggest that a single agency be responsible for providing data that would then be accessible to all interested parties. There are now so many projects that even the consultants are beginning to pool their resources.

The Use of Indicator Species to Detect Change on Coral Reefs: Butterflyfishes of the Family Chaetodontidae as Indicators for Indo-Pacific Coral Reefs

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Introduction

Ecological change often occurs gradually over time. Therefore, long term monitoring research programs are necessary to accurately assess environmental change. This is particularly true when the change is due to small but chronic perturbations to the environment which have a cumulative effect. It should be kept in mind that (1) many ecological processes are slow occurring over a number of years, (2) inter-annual variability is often high, (3) short term studies miss rare but important events, and (4) monitoring only reveals recent historical events.

Environmental change can occur in two directions: (1) from a healthy, pristine ecosystem to a degraded one, or (2) in the opposite direction. Most studies of environmental pollution fall in the first category and there are many examples. In contrast, the present study of the coral reefs at Kaho'olawe, Hawaii, provides a rare example of studying the ecological process of restoration. This adds a further dimension of importance to the research.

Given these truths, a problem presents itself, namely that conventional environmental monitoring by collecting samples for analysis is (1) expensive, (2) labor intensive, (3) requires technically skilled personnel, and (4) is often inaccurate because representative sampling paradigms are difficult to design. Furthermore the method is environmentally obtrusive. Therefore, we are using the coral feeding butterflyfishes of the family Chaetodontidae as indicators of the conditions of the coral reefs at Kaho'olawe. This methodology eliminates the problems noted above for conventional monitoring methodologies.

The objective of the Kaho'olawe study is to conduct an in-depth, longitudinal survey for the purpose of determining the health of the inshore coral reef environment in order to develop information desperately needed in the decision-making process concerning management of this area. An additional objective is to develop an "early warning system" for assessing perturbations to coral reefs. This will be accomplished by demonstrating the use of indicator species of coral feeding chaetodontid fishes to detect low-level, sub-lethal changes in the coral reef habitat. These techniques will serve as an early warning of stress within a coral reef prior to reaching a "point-of-no-return." Hence remedial actions may be taken.

Specifically, correlations of fish feeding preference, abundance, and behavior with coral abundance and health are determined.

Butterflyfishes as Indicator Species

The concept of using certain key species as indicators of ecological conditions is now well established (Soule and Kleppel, 1988). The situation with respect to butterflyfishes is reviewed by Hourigan et al. (1988). The relevant behavioral ecology of butterflyfishes is reviewed by Reese (1991).

A number of points must be emphasized. First, sensitive biotic indicators are most useful when one wishes to detect low levels of chronic pollution such as low levels of chemical pollutants or small changes in temperature or nutrient levels. Over time such low levels of chronic perturbations can have marked detrimental effects on the ecosystem they are impacting. Yet it is extremely difficult and expensive to devise a sampling regime to detect such low levels. It is under such conditions that sensitive biological indicators are most useful. Clearly, one doesn't need a sensitive indicator for episodic, catastrophic events like oil spills or storms. The second point of importance is that not all chaetodontids are candidates for indicator species. The planktivores, in particular, hovering above the reef facing into the current to intercept plankton are not sensitive to the corals on the reef beneath them. Likewise, the more omnivorous species, feeding on benthic invertebrates other than corals and on algae, tend to be opportunistic and they feed on prey in proportion to their abundance. Therefore, as the prey changes, they change their diets and so do not indicate that a change is occurring in the ecosystem.

In contrast, the coral feeding chaetodontids make ideal indicators because they feed directly on the corals. Many species are obligate corallivores and do not feed on anything else. Furthermore, they show strong preferences for certain species of corals which provides a further dimension of sensitivity to the system. Since they are territorial, strongly site attached, and live for many years, they provide a longitudinal component to the system which has great value. Even if changes occur very slowly in the ecosystem which will eventually make the corals moribund, the same individual pairs of butterflyfishes will be present to experience the change.

Current efforts to use butterflyfishes as indicators of coral reef diversity in Indonesia and the Philippines (Nash, 1989; White, 1989) have overlooked this important point. Forty species are listed on their survey form and many of these are not corallivores. To recognize all these species is a difficult task for non-specialists charged with making the surveys, and furthermore less time and attention is given to the distribution, abundance and social behavior of the truly important indicator species, the corallivores. Nevertheless, these efforts are an important start and make it even more important that the utility of the concept be demonstrated in the correct way.

Since all corals on a reef from which the corallivores have departed are not dead, we believe that there is a threshold level of reef deterioration at which the fishes begin to leave, perhaps related to the decrease in both abundance and diversity of the corals upon which they are feeding. Since the size of territories is determined by the amount of coral food contained therein, and since experimental removal of coral from territories results in the pair of fish attempting to enlarge their territory at the expense of their neighbors and results in increased agonistic levels of behavior (Hourigan, 1987; Tricas, 1986, 1989), these changes in social behavior in what otherwise is a stable situation provide a sensitive early indication that changes are occurring. Furthermore, these events which precede the actual exodus of the fish from the reef occur at a time when the corals are just becoming unhealthy but before they have become moribund beyond recovery. Since we are interested in detecting slow changes in the ecosystem, this early warning should provide time for remedial actions to be taken by persons charged with management of the reef reserve or sanctuary, providing the changes are due to perturbations caused by human activities which are impacting the area.

Measurements were made as follows. At each study site four 30 m transects were established. The configuration depended on the reef's contour. At Hakioawa, an expansive reef of fairly uniform coral cover, a star-burst pattern was used. If the reef was a system of raised coral ridges, as at Kuheeia Bay, the transects were placed in a parallel pattern. Since we are interested in living corals and coral feeding butterflyfishes, the transects were purposely placed in areas of high coral cover.

The numbers of each species of butterflyfish within 5 m of either side of the 30 m transect lines were counted. This provided a sampling area of 300 m^2. This was followed by identifying the species of coral at 0.5 m intervals along each transect line. This provided 60 point-intercept data points per transect. Abundance and distribution of the corals and the fishes were calculated.

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Summary of Group Discussion

The Use of Indicator Species to Detect Change on Coral Reefs: Butterflyfishes of the Family Chaetodontidae as Indicators for the Indo-Pacific Coral Reefs

To develop successful monitoring methods, we must eliminate the idea that when in doubt, count everything. We must eliminate the idea that snap-shot sampling is useful. Be critical of existing sampling protocols, and come up with some new indicators — fish, particularly butterflyfish, are closely associated with coral. Because they are mobile, measuring their behavior is a good early warning system.

Management and research should be better related. It is important to develop good working relations with researchers and managers. Researchers can develop the protocol, and managers can evaluate it and help with volunteers. Lab manuals are a great help but should not be sent to the third world without scientific support. Low tech is the way to go; for example, I use nails with a colored tie to mark sampling sites.

So, one, state your questions clearly. Two, select indicator species. Three, develop procedural guidelines; and four, bring in managers to train and supervise the volunteers who will help gather the data. We must have a representative sampling procedure to help us monitor changes that are slow over time and may be seasonal. Know what you are looking for. In the Kahoolawe Monitoring Programs we are looking at site descriptors, coral cover, butterflyfish abundance and coral lipid content. Then we begin looking at comparisons of behavior. Feeding roles and preferences, territory sizes and intraspecies chasing rates. Also it is important to note pairing behaviors. Our conclusions are that butterflyfish can help predict coral changes such as slow chronic perturbations, but our study cannot be used to compare between reefs. It must be site specific. A key point is that changes over time at the same site is the indicator — not just how many species are present.

Coral Reef Health: Concerns, Approaches and Needs

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I. Monitoring Protocols

There are at least 13 handbooks devoted to coral reef survey methodologies (see attachment). In addition, there are several other references that detail techniques on how to measure everything from water motion to coral growth rates (e.g., UNESCO, 1978, Coral Reefs: Research Methods; Univ. Of Miami, 1993: Global Aspects of Coral Reefs, Health, History and Hazards; Univ. Of Guam, 1993: Proc. 7th Intl. Coral Reef Symp.). The pressing need is not in the development of techniques, but rather, in their application. Several modifications and additions to existing techniques are worth mentioning which reflect our recent experience in developing monitoring programs for several Pacific Islands, and which address the needs expressed by regulatory agencies.

A. Choosing methodologies

While there is a need to standardize techniques and their application, this is not always practical. Two major criteria affect the choice of protocols: 1) the question being asked; and 2) the site-specific conditions. If the question is "what changes are occurring on a particular reef?," standard transecting techniques are appropriate. If information is needed on the cause of observed changes, additional protocols are necessary. For example, if the abundance of corals on a coastal reef near a populated area is observed to be decreasing, the cause may be natural variation, anthropogenic disturbance or both. A cause must be identified before a solution can be found. The choice of assessment techniques will also depend on local conditions. From personal experience, ships usually run aground on the most inaccessible, wave-impacted, current-swept, shark-infested waters possible. Transect lines and m^2 quadrats are impractical under these circumstances. Having identified these concerns, there are many standardized techniques that can be selected and applied in a flexible manner.

B. Methods

1. Traditional techniques: shortcomings and suggested modifications. Two key indicators of the state of a coral reef are coral abundance and coral diversity. Sessile, benthic organisms, like corals, are good choices for monitoring, as they will reflect habitat variation. To determine if changes are occurring on a reef due to human activity, an accepted design is the Before-and-After-Controlled-Impact-Procedure (BACIP), which in simplest terms, requires that baseline data be collected prior to the onset of the activity. There are many examples where sewage outfalls or heated effluent discharges have been established, and no "before" data were collected. Consultants are then faced with the task of demonstrating no significant impact with nothing upon which to base this conclusion. A critical point that needs to be clearly understood regarding coral reef studies (or any environmental assessment): Lack of data showing an activity is detrimental to the environment does not mean that activity is safe; it often means there is simply a lack of data. Only data that prove an activity is safe allow a conclusion of no impact. Statistically, this concern is expressed as the potential for a type II error: accepting a false hypothesis. Environmental health is as important as public health (the two being related), hence the same approach used by the Federal Drug Administration (FDA) should be applied to environmental impacts: nothing is approved without adequate data supporting the approval.

In studies of reef health, data on abundance and diversity are important as baseline information to determine if changes are occurring. However, such data alone do not have predictive value. We suggest the addition of age (size) distribution data to quantify larval recruitment. A reef with 40% live coral cover and 36 species may appear to be very healthy. However, if there are no corals in the 1 - 5 year age classes on that reef, something is wrong. Data on coral recruitment patterns are good indicators and predictors of reef health (Richmond, 1993).

Coral mortality alone is not a good indicator of environmental conditions on reefs. There are conditions and events that may have sublethal effects on corals, which cannot be identified using abundance and diversity data. Physiological measurements can be taken which give a better indication of environmental quality and reef health, and may allow for preventive measures to be undertaken prior to reef mortality. These include coral calcification rate, fecundity, inter- and intraspecific competitive ability, respiration rate, protein to lipid ratios, commensal relationships, photosynthetic efficiency, and presence of parasites/anomalies. A physical exam form for corals is suggested (see attached).

In addition to transects and quadrats, the point-quarter method is an effective tool for quantifying coral abundance, diversity and age distribution. This technique has the advantage of statistical rigor, in that there are no zeros in the data set. This is an important consideration in reef assessment, as the design of many studies provide results that show no significant effects even with mortality rates as high as 50%. A consideration in the selection of methodologies is the ability to provide data that are conclusive. If management is to be scientifically based, the science must be sound. It may, however, be appropriate to lower the level of acceptable statistical significance to 70% (p=0.30) rather than the scientifically applied standard of 95%.

2. Development of new techniques.

a. Water quality/bioassays. Decreasing water quality is one of the most important factors affecting coastal reefs adjacent to human populations. Unlike sedimentation-induced mortality which is relatively quick and conspicuous, water quality changes can have more subtle, sublethal effects. These range from reduced growth rates, competitive ability, and fecundity, to interference with chemical communication between hosts and symbionts, conspecifics during reproductive events, egg-sperm interactions, and the response of larvae to specific metamorphic inducers. Bioassays are an accepted method for determining water quality, but are not well-developed for coral reef ecosystems. We are presently studying the effects of pesticides on coral reefs and have found that EPA accepted protocols do not work. Specifically, while concentrations in the water column are "below detectable limits," we have observed statistically significant reductions in larval settlement and metamorphosis rates on appropriate substrata treated with pesticide at a level of 5 PPB. Appropriate protocols that focus on key processes like reproduction and recruitment rather than LC_{50} need to be developed and applied.

b. Reef restoration. Our work on coral reproduction and recruitment has led to the development of techniques for reef-reseeding using planula larvae. In addition to developing methodologies for assessing reef health, a focus should also include techniques for reef restoration. Our work on replenishment of coral populations using mass-cultured larvae has been successful, and compliments work being pursued by Dr. Paul Jokiel at the Hawaii Institute of Marine Biology on the used of transplants for reef restoration.

II. Other Concerns Requiring Coordination at the Federal Level

Discussions with colleagues at Guam EPA and the Division of Aquatic and Wildlife Resources brought up several concerns that need to be considered at the federal level. At present, coral reefs have little protection except in established preserves. It is easier to get a permit to build a structure on a coral reef than it is to get a comparable permit for activities in a wetland or in a mangrove area. Having the Army Corps of Engineers as the permitting agency for construction activities affecting reefs is truly having the fox guarding the henhouse. In the Micronesian region, NMFS and US Fish and Wildlife have been relatively ineffective in protecting reef resources. Part of the problem appears to be the lack of a coherent federal policy.

Federally mandated water quality standards presently in place are inappropriate for coral reef waters. At present, the same standards apply to lakes in Wisconsin, the Mississippi River and coral reefs. Water quality standards do not have a biological component; as written, standards are established to preserve water quality, not the organisms that depend on it. The Non-Point source Discharge Elimination System (NPDES) isn't working. There are more discharge systems in 1995 than there were when this program was enacted in the 1970's to eliminate discharges. Activities over 100m from the ocean, but within a watershed that affects a coral reef, have no marine component to the EIA/EIS monitoring requirements. Additionally, there are no minimum baseline survey standards requirements for coral reef waters.

In summary, it is suggested that regulations be established at the federal level that focus on pollution prevention as a means of reef ecosystem protection.

Acknowledgments

Input from (but no blame to) Dr. Chuck Birkeland (UOG), Gerry Davis (Guam DAWR), and Gary Stillberger (Guam EPA). Grant support from NIH-MBRS.

Summary of Group Discussion

Coral Reef Health: Concerns, Approaches and Needs

There are at least 14 monitoring handbooks already available to coral reef ecologists — it is important to take only the methods from a suite of available methods that fit local conditions. For example, use the Before and After Controlled Impact Analysis (BACIP).

The investigator must determine how much error can be tolerated, especially a type 2 error which is accepting a false assumption as true. What is the confidence level you will accept? Seventy percent certainty or the 95 percent needed to provide scientific certainty? Note the difference between monitoring and prevention. Monitoring is proactive; it goes toward prevention and restoration. Use the Coral reef exam sheet included in this presentation abstract. Tons of pesticides, tested largely with HPLC, go directly into the coral.

Stronger regulations are needed to protect the reef systems. It is easier to get permits for building in coral reef areas than in wetlands, and ship groundings occur too frequently. At the federal level, we lack the necessary laws and standards to protect coral reefs. EPA, NOAA, the U.S. Army Corps of Engineers, Fishery and Wildlife agencies — all have jurisdiction. There are good relationships in some places, but standard regulations are needed.

At present we have no biological standards and no water quality standards either — we are using the same standards provided for surface waters, the Great Lakes and Mississippi River, for example. NTUs don't work — you can be meeting those standards and still have no photosynthesis. What is the water quality? What's underneath? You may have the 1976 EPA nutrient criteria and biocriteria in place and still have a water quality problem.

Can we really say what coral health is? The Coral Reef Initiative should help us determine coral health — or at least support research in that area. It should especially help us to better understand coral spawning habits and habitat. Coral are very sensitive, they can detect the genetic identity of specific sperm, and the reproductive cycle occurs only once a year by an egg-sperm meeting that is chemically mediated and lasts for only one or two days of that year. Thus, if you had regulations banning dredging and tourism one month before and one month after the expected event, you would have a lot of protection . . . a window of opportunity. Likewise, for dumping regulations.

At the peak of the rainy season, runoff is most harmful — watch agrichemicals and pesticides at that time. Golf course runoff seems to be a particular problem. Another factor of concern is the effect of temperature shifts on maturation cycles. Similarly, a 20 percent drop in salinity from fresh water runoff and discharges can cause a 60 to 80 percent drop in fertilization. Octocoral species are sensitive to runoff-borne sediments, red soils, and spawn only on sediment that does not have any pesticide contamination.

To remedy some of these impacts, we can use cultivated larvae to increase coral yield but it is very slow. A 100-year-old reef will take 100 years to regenerate, so prevention is the key. Scientists need to collect life history studies, and volunteers can help do that. We need strong biological and physiological numbers. Right now it appears that if the new generation of coral does not settle in two weeks, it won't.

Two Visually Based Methods for Monitoring Coral Reef Fishes

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ABSTRACT

Two visual methods are described to monitor coral reef fishes. The Roving Diver Technique (RDT) developed by REEF (Reef Environmental Education Foundation) uses volunteers to collect reef fish species presence, frequency of occurrence, and an abundance data. The more quantitative Stationary Sampling Technique (SST) requires more highly trained divers to collect quantitative data on sizes, frequency of occurrence, and abundance for all visually observable species. From these data in index of biomass and importance value can be calculated. Both methods can be used to answer a wide variety of monitoring and scientific questions although each has advantages and disadvantages.

Roving Diver Technique (RDT)

The RDT technique takes advantage of thousands of highly trained divers that are looking for and interesting new challenge. Volunteer divers are trained in reef fish identification using the book: *Reef Fish Identification* by Paul Human and Ned Deloach. On each dive, divers list on underwater slates every species that they can find. Buddy teams are allowed to move freely and search as they wish, but are not allowed to turn over rocks for environmental reasons. Dive time, depth, temperature and other environmental information is recorded. After the dive, and species observed are marked on a preprinted data sheet (Fig. 1) along with an estimate of how many individuals were observed for each species according to the following $\log_{10}$ categories: 1, 2-10, 11-100, or >100. Data sheets are submitted, optically scanned at the University of Miami, and then stored in a data base supported by the Nature Conservancy.

Data analyses primarily is based on frequency of observation using large numbers of dives. Data can show differences in community composition between sites or between seasons (e.g. number of species, individuals and kinds of species) and can show distribution patterns of various species around the Caribbean. Over time, data should show long-term (years) changes in distribution and abundance and could be extremely valuable for monitoring species, such as jewfish and Nassau grouper, that are under protection from fishing.

An indirect benefit of the program is that divers develop a greatly increased knowledge of the marine environment. Divers quickly learn where and what habitats are used by specific species. Trained observers are useful for alerting scientists and managers to problems or unusual changes that might otherwise go unnoticed, such as outbreaks algae or disease, and changes in abundance. Currently over 5,000 divers have enrolled in REEF and over 2,000 data sheets have been submitted in the first full year of the program.

The advantages of the method are its simplicity and avid enthusiasm by divers. Disadvantages are the high variability in searches and differences in skill levels among divers, although data can be edited based on diver experience and other performance criteria. Data collected probably offer less interpretation problems than typical fishery data bases that rely on voluntary and involuntary reporting by fishers.

Stationary Sampling Technique (SST)

Stationary sampling (Bohnsack and Bannerot, 1986) was designed to provide standardized quantitative data on reef fish community structure over a variety of habitat types in an effective and efficient manner. It is based on plot techniques used in terrestrial studies except that visual samples were taken of circular areas by stationary SCUBA divers. At random points on a reef, divers attempt to count all individuals and species within five minutes in an imaginary, 7.5 m (24 ft.) radius cylinder extending from the bottom to the surface. New species are listed while rotating in one direction and scanning the field of view. Except being able to rotate, the observer remains stationary in the center of the sampling cylinder. Five minutes was chosen as an optimum time to determine species presence. It allows sufficient time for most fish to habituate to a diver and to adequately scan all areas, but not too much time to accumulate mobile species initially outside the sample cylinder. The 7.5 m sample radius was chosen to maximize the amount of area that could be adequately searched based on average visibility. The radius was large enough to detect the presence of larger, shy, and economically important species that were unlikely to closely approach a diver, and yet, the smallest species could usually be distinguished at the edge of the sample cylinder. Statistical data are collected for each species including the estimated number of individuals in the cylinder and their minimum, maximum, and mean length.

Species are only listed during the first 5 min with the exception of a few solitary species and highly mobile species in large schools (e.g. Carangidae, Kyphosidae, Scrobridae). Based on previous experience, these species were unlikely to remain in the sampling area and were evaluated when first observed. If individuals of these species were observed later, they were ignored to prevent bias by inflating the importance of highly mobile species.

After the 5-min listing, divers systematically record data for each remaining species working from last to the first observed species. This procedure avoids overlooking a species and avoids bias caused by a natural tendency to count species when they are particularly conspicuous or abundant. This procedure effectively forces counts for each species to be made at random times. Data were recorded from memory for many conspicuous species in which only a few individuals appeared within the sampling cylinder during the initial 5-min listing period. Species always present in the sample area (e.g. Pomacentridae, Labridae, Haemulidae, Scaridae) were individually evaluated by starting at one point on the underwater horizon and rotating 360 degrees while counting all individuals until the entire area was scanned. For species with large numbers of individuals present, fish were counted in multiples of 10, 20, 50, or even 100. Fork lengths were estimated in centimeters by comparing fishes to a ruler attached perpendicular to the end of a 1 m rod.

After recording fish data, divers recorded data on habitat features within the sample cylinder including depth, substrate composition, and maximum vertical relief. Estimated percentage composition of various substrates within the sample cylinder was based on the observer's field of view from the center of the sample cylinder.

The SST method is simple, well-established, and is being used in many areas around the world. It provides quantitative data for most reef species includes a number of variables that can not be effectively collected using other methods. Statistical power comes from large sample sizes. The method reduces bias caused by moving divers and increases the useful bottom time by conserving air. It is best suited for sampling suprabenthic reef species, but is less well suited for cryptic, secretive, and nocturnally active species. It has limited use under conditions of very poor visibility, high surge, and deep depths. A disadvantages is that it provides an index of abundance and biomass but can not easily be used to develop absolute abundance estimates without extensive ground-truth calibration or use of stereo video technology.

Summary of Group Discussion

Two Visually Based Methods for Monitoring Coral Reef Fishes

Two visually-based methods are used in the Florida Keys to monitor coral reef fishes. The first method is the "roving diver technique" (RDT), which uses volunteers and was developed by the Reef Environmental Education Foundation (REEF). A consortium of the Foundation, the Nature Conservancy, and suppliers (those who operate divers' shops) train experienced divers who need a new challenge to add to their enjoyment of diving to observe and report on coral reef fish species. These volunteers use the *Fish Identification Guide for the Caribbean*, a book by Paul Humann (Vaughn Press, 1989) to learn the species. The consortium also offers them articles, newsletters, educational cruises, and supplies (i.e., underwater slates) to encourage their learning and participation in the program.

The methods are simple and the divers enthusiastic. Their effort complements the fisheries-dependent monitoring which concentrates on more commercial information. Fisheries-dependent monitoring does not provide information on all size classes. Volunteer RDT monitoring provides a sampling of everything that can be seen (regardless of its distance away from the swimming diver). A diver makes a visual count, later transferring the count to an identification chart that is then optically scanned at the University of Miami. The reporting categories were prepared by nonscientists in nonscientific terms so that almost anyone can use the form. For example, divers are asked to record how many fish they see by color, or shape, or that have sloping heads or fins.

So far, 5,000 people have signed on, and 2,000 data sheets have been collected. The data sheets contain identifications of fish that cannot be landed, such as jewfish and the nassau grouper that are under protection from fishing. Volunteers look for the largest number they can count, the biggest, rarest, brightest, etc. — all commonsensical categories. Of course, the data must be filtered. The worst problem is erroneous fish — the identification of fishes not really there — and the failure to record fishes that are there. (If the diver cannot identify the fish, he or she may fail to report its presence.) The fisheries dependent data must also be filtered — and it, too, is voluntary. Sometimes the fishers will report what they think will be useful to them commercially.

A second monitoring method used in this area is the more quantitative stationary sampling technique (SST) in which visual samples are taken of circular areas by a stationary scuba diver. A random point is chosen and a species count is taken of a 7.5 meter radius from the bottom to the surface for five minutes. The five minute limit is long enough to observe most fish and brief enough to exclude mobile fish species who are generally outside the area. A meter stick is carried to provide size estimates. The radius can change as long as it is recorded.

The species are first listed, then arranged by categories. Then the habitat — depth, substrate composition, and vertical relief — should be described. This method is best suited by sampling suprabenthic reef species; it is less well suited for cryptic, secretive, and nocturnal species. The stationary point removes the bias caused by a diver's movement and conserves air. This method does not provide an absolute abundance estimate.

Cautions for monitoring programs:

- Getting the number of species is easy; getting the number of individuals in a species is more difficult.
- Talk is cheap; while you monitor change, you must decide what rate of change is acceptable. If a 20 percent degradation is occurring, a manager may be watching the resource go to hell. A species experiencing a negative 20 percent change will need five times its natural survival rate to perpetuate itself; at 30 percent, it will need 10 times its natural survival rate; and so on, up to 100 percent — and this ratio works for every species.
- We must have something to compare our counts to — that is, we must get the data that will put scientists behind the supporters of no fishing areas. Fishing and harvesting of resources are important activities, but they cannot be pursued everywhere all of the time. *The only successful management of these resources occurs when the community gets involved.* There must be a coalition of scientists and agencies and community members in the political process.
- Permanent reserves are highly recommended; sometimes a restriction for several years builds up a species that is then fished out when the ban is lifted. Sometimes a lifted ban leads to a derby that attracts all manner of fishers to the area.
- Know that opposition to restricted fishing areas is greater than the restriction on land uses (hunting areas and seasons), partly because so many people see the ocean as the last great frontier. Boundaries are far easier to recognize on land.

Amphistegina (Foraminiferida) Densities as a Practical, Reliable, Low-Cost Indicator of Coral Reef Vitality

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ABSTRACT

Algal symbiont-bearing foraminifera, *Amphistegina* spp., can provide a practical, reliable, low-cost indicator of coral-reef vitality. These protists are relatively large (1-3 mm adult diameter), reef-dwellers found nearly circumtropically. In their dependence upon algal endosymbionts for growth and calcification, their adaptation to nutrient-poor, warm, shallow-water environments is similar to that of reef-building corals. They live on reef-rubble and on closely-cropped coralline and filamentous algae on reef substrate. When environmental conditions change to favor organisms using autotrophic and heterotrophic nutritional modes over organisms using mixotrophic (algal symbiotic) modes, *Amphistegina* populations decline.

Diatom endosymbionts impart a golden-brown to olive-green color to living *Amphistegina* specimens, making them easy to recognize. These foraminifera can be sampled by collecting reef rubble, scrubbing it, and examining the detached sediment and meiobiota with stereomicroscope, either live or freeze-killed and dried. Under "healthy" reef conditions, *Amphistegina* population densities should exceed 50 living individuals per 100 cm^2 bottom area of rubble. Population densities of 10-50/100 cm^2 indicate cause for concern. Under environmental conditions marginal for reef growth, *Amphistegina* may be present but uncommon (<10/100 cm^2 of rubble.) Living specimens are usually not found in areas where rapid reef degradation is occurring.

Introduction

Amphistegina spp. are among the most common reef-dwelling organisms worldwide. Two species, *A. lobifera* and *A. lessonii*, are abundant on reefs and associated hard substrate environments throughout the Indo-Pacific except for the eastern tropical Pacific.[1] *A. lobifera* lives most abundantly at depths less than 10 m; *A. lessonii* is most common at depths from 5-40 m[2]. Three other deeper dwelling species occur but are not important for this discussion. In Hawaii, dead shells of these two species makes up nearly a quarter of the nearshore sediment;[3] on Kapingimarangi Atoll, their contribution is closer to 90%.[4] In the western Atlantic and Caribbean, *A. gibbosa* is the ecological vicariate of *A. lessonii.*[1]

Amphistegina individuals commonly live on closely-cropped coralline and filamentous algae on reef substrate. They also live on some macroalgae, particularly if there is other epiphytic growth. They are most easily collected from reef rubble, specifically the roughly fist-sized nodules common on and at the base of reef and live-bottom substrata. Population densities are low in the most exposed, high energy, reef margin environments,[2] or where runoff or high bioerosion rates flood the substrate with muddy sediments, where fleshy algae and *Halimeda* dominate the substratum, and where excess organic matter accumulates in the sediments.[5]

Amphistegina individuals host diatom endosymbionts in an interdependent relationship very similar to that found between corals and their zooxanthellae.[6] The golden-brown to olive-green color of the diatom symbionts, combined with relatively large size for foraminifera (1-3 mm adult diameter) make living *Amphistegina* very easy to identify. I have studied their population distributions throughout the world since 1970. Habitat observations made while collecting *Amphistegina*, combined with laboratory observations of the sensitivity of these protists to algal overgrowth, were the basis for the series of papers I have written on why algal symbiosis and mixotrophic nutritional modes characteristic of coral reefs appear to be adaptations to low nutrient environments[7] and why communities shift to predominance of autotrophic and heterotrophic modes as nutrient supplies increase.[1,5,8,9,10]

I sample living *Amphistegina* populations[2,3,11,12] by collecting reef rubble. Population abundances are compared by counting the number of *Amphistegina* collected on a piece of rubble and estimating the area of the bottom covered by that piece. In reef conditions that I, as an experienced diver and reef research, consider aesthetically pleasing and indicating viable reef growth, *Amphistegina* are abundant on reef rubble; typically up to several hundred living individuals can be found on rubble covering 100 cm^2 of bottom (i.e., densities of 10^2-10^3/100 cm^2.) Very early in my graduate career in Hawaii, I discovered that off Honolulu, where disposal of millions of gallons of sewage daily promoted macroalgal growth, *Amphistegina* densities were lower by about an order of magnitude (10^1/100 cm^2.) I never found a living *Amphistegina* in nutrient-stressed south or central Kaneohe Bay.

Since 1981, my research in the Caribbean and western Atlantic has reinforced and refined observations made on Indo-Pacific reefs. With only *A. gibbosa*, population densities in back reef areas seldom compare with *Amphistegina* densities in the Indo-Pacific and overall, densities, tend to be somewhat lower. Yet the same trends are evident. In 1981, I visited the reefs off La Parguera, Puerto Rico, specifically to collect *A. gibbosa* for culture experiments. I quickly found that I could predict my success in collecting living *Amphistegina* by the appearance of the "reef." Though the inner reefs still had substantial coral cover, sponges and macroalgae were obviously taking over. Biota was draped with muddy mucus and bottom sediments were soupy. Rubble, where is could be found, was immersed in the soupy mud or overgrown by sponges. Living *Amphistegina* were rare. On the forereefs of the outer reef arc, I found filamentous algal-covered rubble and resident *Amphistegina*.

The decline of the Florida Keys reefs over the past several decades is paralleled by a decline in the contribution by larger foraminifera to reef tract sediments.[13] For example, in the 1960's, sediment samples were collected from the Florida reef tract by Rose and Lidz.[14] They sampled a transect across a patch reef near Mosquito Bank and dead tests of *Amphistegina* were common, up to 15% of the foraminiferal fauna. Cockey[13] sampled the same transect in 1992 and found that *Amphistegina* tests were rare to absent.

Use of *Amphistegina* as a Bioindicator of Reef Vitality

I propose that densities of living *Amphistegina* spp. on reef rubble can be used as a simple, low-cost indicator of the viability of algal symbiosis as a dominant nutritional and calcification mode in subtropical benthic ecosystems. Because their life span is a few months, these protists respond more directly to environmental degradation than do longer-lived hermatypic corals. Thus, low densities or absence of *Amphistegina* in reef communities indicates that major coral species can also be in jeopardy.

Methods

Field Sampling: On each reef to be examined, a team of SCUBA divers should collect 3-5 samples of 3-5 pieces of reef-rubble (so that rubble covering 100-200 cm^2 of bottom is collected per sample) into labeled plastic bags. Preferred depths for sampling reefs exposed to ocean waves are 8-20 m (*Amphistegina* densities are typically low in very high energy environments); shallower samples can be collected in lagoonal, backreef or patch reef environments. Samples should be kept shaded in a bucket of water until they are taken to the laboratory for examination. Samples can be examined either live or quick-killed and dried, depending upon field-laboratory facilities and field time available.

Live Examination: This easiest and fastest technique if a stereomicroscope is available at the field-laboratory site. Place a sample containing the 3-5 pieces of rubble in a small bucket (2-3 liter), and scrub each piece of rubble with a small brush (e.g., a vegetable brush or toothbrush) to remove attached filamentous algae and foraminifera. The rubble pieces should be set aside for bottom-area estimation (see below.) Rinse the sediment/algae slurry several times with seawater, decanting off the muddy sediments until the water on the sample is clear. Pour the slurry into a 150 x 20 mm petri dish, disperse the sediment and cover it with at least 1 cm of water. Place the dish under low light, covered and undisturbed, for at least 12 hours. The living *Amphistegina* will crawl to the top of the sediment (and often up the walls of the dish) and can be readily identified and counted using a stereomicroscope at 20x magnification. Because abundances vary logarithmically, all specimens need not be counted, only the first 100 with an estimate of the percentage of the dish examined to find 100 specimens. A technician will quickly learn to distinguish among "absent," "uncommon" (<10/100 cm^2), common (10-50/100 cm^2), and abundant (>50/100 cm^2.)

After live examination, samples of sediment and foraminifera should be quick killed by chilling or freezing, washed with fresh water over a 63 μm mesh sieve, dried on filter paper (coffee filters are ideal because they are tough and inexpensive), dried at 40-50° C overnight, and stored in labeled, small zip-lock bags or vials. If desired, these samples can be used for more detailed analysis of shelled micro- and meiofauna at a later time.

Dead Examination: Samples can be killed whole or after scrubbing, by freezing or quick-chilling, which will preserve the color of living *Amphistegina*. After killing, samples should be washed in fresh water over a 63 μm mesh sieve, placed on filter paper and dried at 40-50° C. Rubble pieces dried intact must be scrubbed before examination. Dried sediment should be examined in a black picking tray or in a clear tray with black background. Golden-brown *Amphistegina* specimens (indicating that they were alive when collected) are to be counted. Bottom area covered by rubble should be estimated by the method described below.

Bottom area estimation: Bottom area covered by each piece of rubble can be determined in one of several ways:

a) by tracing the rubble onto graph paper and determining the area within the trace for each piece (useful if a computer digitizer or scanner is unavailable.)

b) by tracing the rubble perimeter onto paper and, when convenient, measuring the area of the trace using a computer digitizer (useful if a computer digitizer or scanner is available, but not at the field-laboratory site.)

c) Directly measuring the area covered by the rubble pieces using a computer digitizer or scanner (useful if the computer system is available at the field site or if the rubble samples are taken back to the permanent laboratory.)

Data Analysis and Interpretation: Sample data will include a) date, b) reef name and coordinates, c) short visual description of site and samples, d) bottom-area covered by each sample, e) number of *Amphistegina* found in each sample, and f) density rank of each sample [#4: d >100 *Amphistegina*/100 cm^2; #3: d= 50-100/100 cm^2; #2: d= 10-50/100 cm^2; #1: 0< d <10/100 cm^2; #0: d = 0].

If samples are from a forereef site, 5-30 m depth, or from a backreef site in the Indo-Pacific, and the majority of the samples rank 3 or 4, environmental conditions at the site are conducive to algal symbiosis and mixotrophic calcification. If all samples rank 1 or 0, the site is not conducive to algal symbiosis, so if the site is valued as coral reef habitat, mitigation procedures should be initiated. If the majority of samples rank 1 or 2, conditions are marginal, so if the site is valued as coral reef habitat, mitigation procedures should be considered.

If samples are from a backreef site in the western Atlantic or Caribbean, a density rank higher than 2 is unlikely. Presence of *Amphistegina* indicates environmental conditions at the site are conducive to algal symbiosis and mixotrophic calcification, while absence may be cause for concern but must be accompanied by other data.

Time Requirements: Depending upon sample depths and distances between reefs, 2-6 reefs can be sampled per team per day. Sample processing requires 0.5-1 hr/reef and bottom area analysis 0.5-1 hr/reef. Live examination requires up to 2 hr/reef; dead examination approximately 2 hrs/sample.

Sampling Frequency: Samples should be collected quarterly during the first year of field monitoring to determine seasonal variability in population density. Subsequently, sampling should be once or twice per year.

Training Requirements: I can train a technician to field sample, to identify *Amphistegina*, and to process and analyze samples in two successive days.

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Summary of Group Discussion

Amphistegina (Foraminiferida) Densities as a Practical, Reliable, Low-cost Indicator of Coral Reef Vitality.

One of the most common reef-dwelling organisms, *Amphistegina* spp., which depend on algal endosymbionts, can be used as an indicator of coral reef vitality. Because *Amphistegina* are found throughout the tropics and host golden-brown to olive-green diatom-symbionts, they are easy to recognize, and can be obtained by scrubbing reef rubble, then taken live or freeze-killed and dried. They are not usually found in areas of rapidly degrading reef, but should occur in the order of several hundred individuals to each 100 square centimeters of bottom rubble (but their numbers are lower by half a magnitude where sewage has been dumped.)

Amphistegina respond more directly to changes than do longer-lived hermatypic corals. Absence of the Amphistegina may indicate that major coral species are in jeopardy from nutrient enrichment. To collect live samples of *amphistegina*, we should collect three to five samples of reef rubble; they can also be predicted from the condition of the reef and found in sponges, macroalgae, and soft bottom sediments. Keep the samples in water until they are removed to the laboratory and cleaned. Then put the samples into a petrie dish under low light. *Amphistegina* will crawl out and up from the bottom of the dish.

The first hundred should be counted, but it soon becomes easy to see if they are absent, uncommon, common, or abundant. After the count has been completed, the samples may be frozen and kept for other analyses. If dead samples are used, freeze drying preserves their color for easy identification. Methods training includes field sampling by divers, processing, selection of bottom areas, data interpretation, time required, and sampling frequency. Grab sampling can also be used to collect the organisms and then, live or dead examinations can be made for analysis. Technicians can be trained to process and analyze samples in two days. Samples are taken twice a year, then converted to an index score for each site (4 = over 100 counted; 3 = 50 to 100; 2 = 10 to 50; 1 = up to 10; and 0 = none found).

Monitoring Methods for Assessing Coral Reef Biota and Habitat Condition

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The spatial complexity, patchy distribution of organisms, multi-levels of organism spatial occupation (canopy, sub-canopy, and substrate), lack of adequate base line information, and rigors of operations, often in remote and isolated areas, challenge the investigator in sampling the coral reef community. Multiple use of the habitat for fishing, boating, diving and society's awareness of the beauty and uniqueness of coral reefs dictates the use of non-destructive sampling methods. In our area, it would be out of the question and unethical to use destructive sampling methods on coral reefs that support a dynamic tourist operation.

Federal programs mandate quality assurance — quality control in respect to sampling accuracy and data processing. The problems of taxonomic determination and observer biases must be addressed and a standard for accuracy must be developed.

The Florida Department of Environmental Protection, Florida Marine Research Institute, is responsible for conducting damage assessments on coral reefs and for monitoring coral reef habitat areas. The principal focus is in southeast Florida (Monroe, Dade, Broward, and Palm Beach Counties). Environmental assessments include hurricane perturbations, winter storms, bleaching episodes, vessel groundings, dredging insults, oil spills, aircraft crashes, and fishing gear problems. The following is applicable to sessile epibenthic biota. Space and time do not permit discussion on mobile invertebrates and fish; see Rogers et al. (1994), English et al. (1994).

We use a multitude of techniques to evaluate and assess injury to reef resources. In the larger scale evaluations, aerial photogrammetry, ground truth surveys, and Global Information System (GIS) mapping are applied. The most common techniques used for *in situ* evaluations include transect, quadrat, 35 mm photography, and video. For trace metal and pesticide evaluations sediment and organism samples are collected for laboratory analyses. For disease and bleaching evaluations we collect organisms for histopathology and electron microscope studies.

We began to monitor coral reef habitat in the Florida Keys in 1978. Methods we have used include quadrats (Manton and Stephenson 1935), continuous line transects (Loya 1972), and photography (Bohnsack 1979, Done 1981). We applied video initially in 1989 (Jaap et al.

1990). Your request for a practical and expedient sampling method is perhaps a search for the Holy Grail. At a Fisheries Management Council Meeting I attended, a wise fisheries scientist (Gordon Gunther) told the gathering that from his perspective developing the Maximum Sustained Yield (MSY) for a fishery was like the search for the Holy Grail; it was always beyond reach. The quest was important; we strive for the goal and in that striving we make progress. The same may be said of the search for a practical-economical-universally-robust sampling method for coral reefs. We embrace Ohlhorst's and Liddell's (1994) warning, "different sampling methods serve different needs and that certain methods are less satisfactory than others, depending on community structure."

Public Law 101-605 created the Florida Keys National Marine Sanctuary (FKNMS) and a Water Quality Protection Program (WQPP) for the FKNMS. Monitoring of the environmental parameters and specific resources including mangroves, sea grass, and coral reefs is a major component of the WQPP (EPA 1994). Following a year of negotiations, a coral reef and hard bottom habitat sampling program is now agreed upon. The Sampling methods we selected are of a robust nature and they were approved by three independent review panels. We offer them as a point of departure.

We selected quadrat *in situ* mapping and measuring (Weinberg 1981) and video transects (Carlton and Done in press). Our sampling sites were selected using the E-map stratified random methods (Overton et al. 1990). At each sampling site (N=12 offshore reef, 10 patch reef, and 9 nearshore, hard bottom sites), we will sample twenty 1 m^2 quadrats and 160 m of video transect.

A quadrat is a unit of area; typical quadrat sample sizes include 0.25, 0.50, 1.0, and 2.0 m^2 area (organism size and dispersion are variables that need to be considered in sampling design). The quadrat perimeter is defined by a frame (use PVC pipe to construct cheap and robust quadrat frames). The positioning of the quadrats should avoid overlap and shared boundaries to prevent auto correlation and parallax problems. Some quadrat sampling methods include counting and identifying the organisms under an X, Y coordinate grid (planar point intercept), estimating the cover using a grid of squares, and mapping the distribution of the taxa of interest within the quadrat (*in situ* mapping). These data will render information on abundance, cover, and sinsity. The statistical offering includes mean, range, frequency of occurrence, and variance. Ecological computations can render dispersion, diversity, similarity, dominance, evenness, principal component analysis, classification, and ordination. For repeated measurements (a time series), we believe that the quadrat provides a better reference than a transect. The rigid frame of the quadrat coupled with a reference system provide better accuracy for re-deployments than a line or chain transect.

Use of a quadrat is a traditional sampling method (Manton and Stephenson 1935) that is cheap, flexible (in the context of what and how to sample), and provides relatively good repeatability. We inventory the stony corals (Milleporina and Scleractinia) and echinoids at the best possible taxonomic resolution, while sponges, anemones, zooanthids, corallimorphs and octocorals are counted at a lower level of taxonomic resolution. Stony corals 30 cm and smaller are measured. We tested the sampling efforts of two observers (Jaap and Porter) to inventory the same quadrats and found good concurrence. Sampling conditions during the test were a challenge (poor visibility, cold water temperature, and moderate wave surge). Statistical tests (analysis of variance model and non-parametric) reported that the two observers were equivalent in reporting the relative abundance of the taxa.

Video transect sampling is a significant improvement in efficient data collection compared to conventional quadrat or transect sampling. The camera sampling rate (hi band 8 mm format) is 1,800 image frames per minute. Video resolution is approximately 400 lines. For optimal resolution the camera should be less than 50 cm from the reef surface and artificial lighting should be used to illuminate the subject area. The camera uses a reference rod to keep it a relatively even distance from the reef surface. We swim the camera system across a 20 m distance in 4 to 5 minutes (r to m/minutes). Images are frozen on a monitor and a series of random points on a transparent overlay are used to determine the relative species abundance or cover (Curtis 1968). Our testing indicates that there is equivalency of data collected with 35 mm photography and video.

Our favored analyses for time series data sets include the univariate K-Dominance curve, multivariate, non-parametric classification analyses, and multidimensional scaling (MDS) ordination. These techniques are well documented and recommended by several statisticians for coral reef applications. The MDS tests can be used to compare biological and physical-chemical information. A plot of the information will exhibit strongly correlated attributes (Clarke 1993).

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Summary of Group Discussion

Water Quality Protection Program for the Florida Keys National Marine Sanctuary Phase III Report, Implementation Plan for Water Quality Monitoring and Research Programs

"Truth," someone once said, "is the intersection of independent lies." The search for a practical, economic and universally robust sampling method is a search for the Holy Grail, according to Gordon Gunther. Florida has been looking for the Holy Grail since 1978. We have not found it yet, but we have found many interesting things along the way.

Changes do not always mean degradation. Our sampling procedures include traditional quadrat methods wherein the quadrat is defined by pvc pipe frames. We think the quadrat is easier to resample and better than a transect. Whatever method is decided, it must be nondestructive because we are located in an area of high tourism. Boating, fishing and diving are abundant here, and the beauty of the reefs must always be respected. Problems in sampling the reefs are their spatial complexity, patchy distribution and the multiple levels of organisms to be sampled. We must certainly have quality assurance and control and standard methods to ensure accuracy.

We assess hurricane ravages, winter storms, bleaching episodes, dredging results, spills, aircraft and fishing gear damages, using large-scale evaluations, aerial photography, and ground truth surveys. In situ evaluations may be transects, quadrats, 33mm photography, and videos. Sediments and organisms are tested for trace metals and pesticides and submitted to additional pathological and electron microscope studies. We use random samples — at least 30 at each site — and aerial photography to get a handle on habitats. We use E-Map stratified random methods to find sites.

Included in our samples are environmental qualities, meteorological and physical data — light, salinity and temperature are collected from E-Map stations on an hourly basis. The data go directly to the Internet, but we do not yet have same sampling procedures everywhere that would allow us to link the data.

A map of our sampling area, from Key Largo to the Dry Tortugas is attached to this report. Poor visibility, cold water temperatures, moderate wave surges and up welling during active reproduction modes add stress . . . found octocoral and stony corals in some places . . . evidence of internal waves, cold water spikes five or six times a year — in the region of Dry Tortugas.

In the northern part of the Keys, octocorallia were hit by disease in 1983 and 1984 — they are coming back but only very slowly. The problem was a cold water disease — or at least most people think it was a disease. At Sombrero Key, we compared monitoring data/conditions and got a near 85 percent concurrence of data submitted by trained and volunteer monitors — virtually identical results!

Also attached to this report are figures representing our video transect apparatus. Video systems so many frames per second, analyzed using random dot patterns — digitizing the area is too time-consuming and too expensive. We are still seeking low tech measures for use by all kinds of agencies. Archiving photos is also time consuming — CD-Rom data will eventually be available in perpetuity — stereoscopic analysis was tried, but too time consuming.

In terms of monitoring designs: We must know the question we are asking, and we must stop thinking that counting everything is the best way to go. The time from data collection to data analysis grows inversely, and raw data is hardly usable for management objectives. I think the question to ask is this: "what is stressing these communities?"

Monitoring and Assessment of Coral Reef Health: Coral Disease Incidence and Cyanobacterial Blooms as Reef Health Indicators

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Coral reef habitat degradation includes chemical, biological and physical factors. This presentation will focus on two of the biological aspects of coral health: coral diseases, and the interactions between cyanobacteria populations and overall reef vitality.

I. One of the most important (but little studied) aspects of reef degradation is coral disease. Several specific diseases have been characterized, and consist of the band diseases (black band, white band, and red band); coral bleaching; and tumor formation. In addition, general uncharacterized states of coral ill-health have been described ("mottling", etc.). Most research to date has been carried out on black band and bleaching, although many important questions remain unanswered. An overview of the diseases (with emphasis on black band) will be presented.

In terms of coral reef health, black band disease is more harmful than bleaching due to the fact that most corals maintain viability and recover completely from bleaching whereas black band actively kills coral. Our data from the Florida Keys show that black band disease is clumped in distribution, which suggests that the disease is infectious. These results contradict the only other published study of black band disease incidence (Edmunds, 1991) in the US Virgin Islands — here it was found that black band disease was not clumped.

Significance of Black Band Disease to Coral Reef Health

(a) Coral Death. Black band migrates across corals at rates often >1 cm/day, completely lysing coral tissue. Susceptible colonies typically grow at rates of 1 cm in circumference per year. The result is that colonies which become infected very often die. Many of these corals are hundreds of years old.

(b) Affect on the Reef. We continually observe "hot spots" of black band disease activity. The worst two sites in the Florida Keys National Marine Sanctuary are Looe Key and Grecian Rocks. One site at Grecian consists basically of large dead *Montastrea annularis* colonies, with obvious loss of juvenile fish habitats. Certain reefs exhibit year round, ongoing black band infections, whereas other reefs will have multiple infections one year and none in subsequent years. Very recently (since 1993) a few reefs of the Florida Keys exhibited year-round black band, an apparent new "low temperature" form which allows coral death to occur year round. These corals have much less of a chance to "recover."

(c) Important Unknowns.

■ Causative Agent. The black band community consists of a microbial consortium. All members of the consortium have been proposed as the disease agent, including associated heterotrophic bacteria; fungi; and the cyanobacterium *Phormidium corallyticum* ("recognized" as the causative agent, but no pure culture experiments done). The causative agent has thus not been identified.

Transmission in the natural environment and route of infectivity. We have recently found *Phormidium corallyticum* not in association with black band. As part of a survey (sampling and microscopy) of the distribution of cyanobacteria on reefs of Key Largo, *Phormidium corallyticum* was found in 9 of 82 samples (all from small sediment patches in indentations of live coral colonies). We did not observe any of these to develop into black band.

■ Relationship to Environmental Quality. We are analyzing black band disease incidence vs. the following environmental parameters: nutrients (N and P compounds); temperature; light; turbidity; salinity; coral cover; coral diversity. Data analysis (200 sites) is in process. Observationally, there is no clear correlation.

■ Long term effect on coral. When coral are only partially killed by black band, some of the skeleton remains exposed. While it has been suggested that this is a beneficial mechanism to provide new substrate on reefs for new coral, we routinely find that exposed areas develop fungal/microalgal turfs. We have observed three colonies in which fresh coral tissue grew back over the exposed colony (previously unreported).

II. Very little research has been performed on the relationship between cyanobacteria ("Blue Green algae") and reef health. Traditionally, the appearance of blooms of cyanobacteria in aquatic ecosystems is considered to be an indicator of eutrophication (nutrient enrichment), which is a severe water quality problem. This is due to the fact that the two main limiting nutrients in aquatic ecosystems are phosphorous and nitrogen. When phosphate enrichment occurs (sewage influx, agricultural runoff, atmospheric deposition, etc.), there is a competitive advantage for nitrogen fixing cyanobacteria, which often bloom. These blooms, besides exhibiting often undesired biomass and a very real danger of toxin production, also serve as a source of fixed nitrogen to the ecosystem, so now both limiting nutrients are being input into the system. The most dramatic example on reefs has been the blooms in Hawaii associated with sewage.

In the Florida Keys, we have observed two recent cyanobacterial bloom scenarios. One reef (Algae Reef) developed dense blooms of two species of the cyanobacterium *Lyngbya* in summer of 1989. The bloom occurs as long (0.5 m) strands of the filamentous alga attached to virtually any attachable substrate. Primarily soft corals and gorgonians are affected (the filaments can't attach to the smooth surface of scleractinians). Corals covered with the dense blooms are extremely light and oxygen limited, and die. Toxin is not produced (samples have been analyzed). We estimate that >90% of the soft coral in this patch reef is dead, with an affected area of approximately 200 by 300 m2. The problem has since spread to another reef (Horseshoe Reef) 0.75 nautical miles south of Algae reef. Again, *Lyngbya* is covering and killing all soft corals in rapidly expanding areas. We do not yet know if there is an environmental degradation correlation, but have measured active upwelling of interstitial water at both reefs. The *Lyngbya* do not fix nitrogen during the months of October or November, but may during the summer months. One year (1991) a black band "hot spot" developed in the middle of an affected area of Algae Reef.

The second cyanobacterial event has been the development of a thick turf of a heterocystous nitrogen fixing population at Grecian Rocks (fall of 1994), precisely at the hottest year round black band spot. This **may** be due to upwelling of phosphate from sewage from the Florida Keys. We are following this bloom and are measuring nitrogen input to the reef. If such blooms become more prevalent, this is a sure indicator of eutrophication.

Proposed Methodology

Methods for monitoring coral disease and cyanobacterial blooms are very simple and cost effective, and at this point (due to the many unanswered scientific questions) may be limited to ongoing underwater surveys. As black band (and white band) are very visual and obvious, programs should be in place where divers routinely report disease incidence. Simply counting and identifying corals is a good start.

Conclusion

At this point in time, a program should be initiated to monitor and document coral disease incidence on a seasonal basis. The program should focus on black band and white band (colonies counted and identified) and description of bleaching events.

Any cyanobacterial bloom should immediately be reported. Samples should be collected, and the site should be photographed and monitored for spread. There should be an immediate investigation into the possibility of sewage contamination to the affected reef.

Summary of Group Discussion

Monitoring and Assessment of Coral Reef Health: Coral Disease Incidence and Cyanobacterial Blooms as Reef Health Indicators

Reef degradation can result from biological factors: coral diseases, coral bleaching, and the interactions of cyanobacteria (bluegreen algae) with other reef factors. Band diseases — red, black and white band diseases — are more damaging than coral bleaching and mottling (general coral unhealthiness). Black band causes total coral populations to die in about two months. Red band spreads out over the coral in the daytime and recedes to a red band at night. It is very slow moving, and we usually see it only in patches.

White band disease moves very fast, and has been known to wipe out 100-year-old coral species. Cyanobacteria are found on Key Largo in association with black band disease, but we still cannot say that it is the causative agent. Black band was found in clumps in the Florida Keys; the only other study said it was not clumped — and therefore not infectious.

We are still trying to figure out the causative heterotrophic bacteria — a bacterial disease not all patches of which develop into black band disease. White bands in the white band disease seem to contain oxygen and sulfur, so the area below it would seem to be an anoxic, sulfide rich substrate. Aspiration will remove black band disease — and scraping is about 90 percent successful. It can also be vacuumed off. The black band can be dug out and clay applied to the coral to protect it.

Black band disease is monitored at 200 sites and attempts have been made to correlate it with environmental quality data: salinity, light, nutrients, turbidity, depth, temperature, coral diversity and cover. So far, little correlation has been noted. Black Band Disease causes coral death, fish habitat loss, and overall coral habitat degradation. Its cause is unknown, as is its mode of transmission, incidence and abundance, and long-term impact on reefs.

Cyanobacteria seem to be found in nutrient enriched waters — especially in areas with reverse nitrogen to phosphorus ratios. Cyanobacteria blooms were first noticed in New England. They may be correlated to global climate change and the up-welling of phosphates from sewage. They not only indicate nutrient enrichment, they may also lead to dual nutrient loading (as they increase nitrogen fixation processes). Cyanobacteria smother the coral; they also have a potential for toxin production and lead to habitat degradation.

Key Corals usually recover from coral bleaching. Bleaching is episodic and natural, but very heavy mortality follows bleaching events.

Our conclusion is that coral diseases and cyanobacterial blooms should be included in monitoring protocols because they are reef health indicators. The condition of the coral will have some effect on the severity of acute, high level natural occurrences and anthropogenic stresses on the reef — though it is only the anthropogenic stresses that we can hope to control.

We should monitor and document coral diseases on a seasonal basis and observe and report all increases in cyanobacterial biomass. Underwater surveys should be initiated to count the number of black and white band diseased coral colonies and to identify the coral species affected, the number of colonies, and the incidence of bleaching. The monitoring should continue on a seasonal basis — the same stations or transects should be observed every two months — and a black band vacuuming program should be included in the protocol. Volunteers can help report and pinpoint coral diseases with very little training.

Water Quality Characterization and the Health of Coral Reefs

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Coral reef systems are unique in their ability to maintain high biomass and diversity of organisms in spite of occurring predominantly in low nutrient (oligotrophic) environments. The 'secret' of their success lies in the diversity of symbioses between animals and single-celled algae (zooxanthellae), particularly of reef-building corals, that recycle and conserve nutrients, and in the abundance of low-nutrient adapted free-living algae (mostly turfs but some fleshy) that form the base of the coral reef food chain by being heavily cropped by reef herbivores. On healthy, accreting reefs, the slow-growing reef-forming corals and calcareous algae dominate much of the open substrate, while the faster growing turf algae are kept in check by the combination of grazing and low nutrient supply. Thus, a "healthy reef" can be characterized as one with high cover of corals and short algal turfs and low cover by fleshy algae. The recent concern about the degraded health of coral reefs is a result of observations that many coral reefs, especially those near larger human population centers, are shifting away from this description towards communities dominated by diseased corals and high cover by macroalgae, especially species that overgrow corals. The question then is how can we determine the factors responsible (causes) for coral reef degradation, and how can we reverse the trend?

The factors most commonly blamed for coral reef degradation are: nutrification, sedimentation and over-fishing. When nutrient supplies increase (=nutrification), the delicate coral-macroalgal balance can be undone, resulting in fleshy algae (usually different species than those that occur normally in turfs) overgrowing the corals. When this situation continues over prolonged periods, the coral reef can deteriorate into an algal covered limestone pavement. This scenario, the eutrophication of coral reefs, has been considered by reef scientists to be among the top two greatest anthropogenic threats facing coral reefs world-wide (workshop reports edited by D'Elia et al 1992; Harwell 1992; Ginsburg 1994 and several others), leading to a need for better ways to assess the nutrient status of reef areas. The other major threat is overfishing, which by removing important algal grazers can favor the competitiveness of algae over corals. Increases in coastal sedimentation, caused by changes in coastal land use patterns, dredging, etc. can have a similar effect of a shift from corals and corallines to fleshy algae, because algae appear to tolerate sedimentation stress, abrasion and reduced light availability better than do corals, and sediments usually bring with them a nutrient load.

Anthropogenic nutrification is not necessarily easy to recognize. Changes in herbivory can both make nutrification hard to detect as well as emulate its effects. On the one hand, the impact of nutrification can be ameliorated or delayed by herbivorous fishes and sea urchins that keep the algae grazed down. On the other hand, overfishing, coupled in the Caribbean reef province with the near extinction of the major reef urchin species *Diadema antillarum*, has been shown to result in reefs becoming overgrown with algae without any known change in the nutrient flux. Any form of stress that kills corals (bleaching, disease) will in the short term be followed by algae overgrowth of the exposed skeletal surface. It is almost impossible to distinguish after the fact between a dead coral killed by algal overgrowth from one where the algal overgrowth followed death. Furthermore, except very close to the source, increased nutrient concentrations are not measurable during the early phases of eutrophication because they are so quickly taken up by (mostly benthic) biota. It is easier to recognize eutrophication when it occurs close to human activity but difficult to identify with any certainty over larger spatial scales, especially since in most reef areas the natural nutrient regimes are poorly understood, and the anthropogenic inputs may be small compared to the natural signal (e.g. sewage inputs to Florida Keys compared to upwelling inputs).

This presentation will concentrate mostly on the degraded water quality problems caused by nutrients and their detection. There are three consequences of increased nutrient inputs that may be useful as indicators of eutrophication, and that may be measurable by a combination of simple, inexpensive and more sophisticated approaches (e.g. remote sensing techniques). Especially in oligotrophic areas, nutrients don't stay in the dissolved inorganic form for any period of time: they get taken up by either phytoplankton or benthic macro and microphytes. In order for measurements of nutrients to be useful for identifying sources (and making decisions about how to prevent the enrichment) measurements need to be made **near the source**. Within a few hundred yards or less of small point sources, the nutrient concentrations will be down to background due to dilution and biological uptake (see for example studies by D'Elia et al 1981 of groundwater seepage on Jamaican reefs, Hatcher and Larkum on enrichment studies on Great Barrier Reef, Lewis 1985 for groundwater seepage in Barbados, Lapointe *et al.* in studies of Belize mangrove cays with bird rookeries). Where circulation is slow and residence time higher, increases in water column chlorophyll may be one of the effects of nutrient enrichment that could be inexpensively measured by water sampling, and over larger spatial scales, observable with remote sensing. Where there is shorter residence time, phytoplankton biomass may not have a chance to build up (or may be rapidly grazed), and water column chlorophyll may not be indicative. Once nutrients enter the biological realm, they become part of the biogeochemical cycle of the system. In oligotrophic areas, the major nutrient pools are either the biota or detrital/sediments. Therefore, the places to look for nutrient enrichment at any distance form the source is in the benthic biota, or in the sediment/detritus reservoir which is the major nutrient source for benthic producers in shallow water systems. Kaneohe Bay coral reefs were being impacted by algal overgrowth of both soft-bottom and reef areas long before high water column nutrient concentrations were evident, and the sediments served as a reservoir to prolong the impact long after sewage was diverted. Changes (increases towards the offshore) in the landscape-level distribution of seagrass and algal beds, seagrass epiphytes, or in the species composition of benthic plants and algae (indicator species, elemental composition) are other ways in which *in situ* and remote sensing techniques could help detect nutrification. Possibly the best way to detect nutrification patterns is by sampling of sediments for their nutrient loads because these are the reservoirs from which the benthic plants get their nutrients and will integrate both the temporal and spatial scales of nutrient inputs. This can be done by collecting sediment cores along transects from suspected sources to reef areas, and analyzing the sediments for total nitrogen and phosphorus content. As with any other approach, the "norm" for the particular location needs to be determined by selecting reference sites with which to compare values from the suspect sites. Sediment nutrients have an advantage over water sample nutrients in that sediment subsamples can be dried and shipped to laboratories for analysis with minimal concern for sample degradation.

The Florida Reef Tract is an environmentally sensitive area of great ecological and economic importance, recently recognized by the creation of the Florida Keys National Marine Sanctuary. Nutrification of reef tract waters is the number one water quality concern presently being addressed by NOAA, EPA and the State of Florida in the design and implementation of the FKNMS Water Quality Plan. For the reasons described above, it has been difficult to agree on the degree of past and present eutrophication of the reef areas even though eutrophication of inshore waters is widely acknowledged. This area would be an ideal location in which to test the effectiveness of the various assessment approaches described at this workshop for determining whether there is a proximal cause for the degradation of Florida coral reefs.

Summary of Group Discussion

Water Quality Characterization and the Health of Coral Reefs

Although it is difficult to distinguish between natural trends and human impacts, it is safe to say that the most important environmental problems impacting coral reefs are nutrification and overfishing, followed by turbidity; temperature changes; pesticides, metals and hydrocarbons. On a localized basis, eutrophication is easy to pinpoint (at sewage outfalls, for example); on broader scales, we have a high degree of uncertainty — for example, are problems caused by Diadema die-off or by the harvesting of herbivorous fishes? In both cases, water quality is a switch that helps or hinders community composition, and community composition may also be modified by herbivory pressure. Sewage may not always be bad for coral reefs. That is, high nutrient levels may encourage growth though perhaps of fewer coral species.

We can assess nutrification by looking at nutrients in the water column, algal composition, and sediment nutrients. Algal monitoring is more difficult and requires more training than some sediment nutrient monitoring. Water column changes, benthic algal composition ("you are what you eat"), and sediment nutrients must be monitored. The sediments are especially useful because they provide a high amount of data for a low cost. Water chemistry is also important but some countries do not have the expertise to sample it.

Nitrogen and phosphorus are especially telling — off-shore nitrogen gets used up, and phosphorus predominates. We should get sediment cores, subsample porosity, then extract pore waters and send samples to labs. Biogeochemists must complete nitrogen samples quickly to determine how nitrogen changes from land to ocean. In carbonate waters, for example, is the phosphate at high levels? Or do we expect phosphorus to be limited in carbonate waters?

A problem for Florida reefs may be a loss of nutrients — St. Croix has a high nitrogen and phosphorus content. We must determine what is normal in an area and what the sampling procedure should be . . . chlorophyll is a good marker for nutrients in general, plant life cycles are short-term, sediments are close to the problem, and coral reefs are linked. We can't look at the reef only, but must also look at the sediments. Are sediments sinks for nutrients? How is phosphorus related to water quality and what causes the up welling of nutrients — are they flushed to the reef?

It is also important to pick out the regeneration rate and to know what the no observable effect limits (NOELs) might be. Nonpoint source-contaminated groundwater should be discernible in waters but it is not the concentration of nutrients that is important, but what happens to them — the subsequent eutrophication of the waters.

Reef Fish Monitoring and Assessment at the Marine Resources Research Institute (MRRI)

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Methods used at the MRRI to assess and monitor stocks of reef fishes include a variety of removal and non-removal sampling techniques. A non-removal diver census of fishes inhabiting three habitats (backreef, reef crest/cut, and forereef) on the barrier reef and two offshore atolls of Belize indicated differences in relative abundance of dominant and economically valuable fishes among habitats and between marine reserve and unprotected areas. The forereef had the greatest number of species, but diversity (H') was highest in the cuts. Fish abundance was also greatest on the forereef. In atoll forereef and barrier reef cut habitats, individuals and species per observation were greater in protected areas, which also had greater abundances of commercially important fishes. Many herbivorous species were more abundant in unprotected areas, perhaps due to predator removal by fishing.

Visual census methods (remote video) have also been used map and quantify reef fish habitat in the South Atlantic Bight (SAB, from Cape Lookout to Cape Canaveral). Visual census data have been combined with sonar data and collection data on indicator reef fishes to map reef fish habitat in the SAB.

Another non-removal sampling method being used to assess SAB reef fish stocks is fish tagging, which is aimed at assessing fish population sizes (black sea bass) in sanctuaries, documenting spawning migrations, and examining movement of fishes (e.g. gag, greater amberjack, white grunt, etc.). Non-invasive tissue sampling is also being conducted on tagged SAB reef fishes to assess stock identification and spawner-recruit relationships. In addition, we are assisting other investigators in developing non-invasive methods for determining sex and maturity of groupers.

An annual monitoring survey, based on removal (fish trap) methods at random stations throughout the SAB has been used by the Marine Resources Monitoring Assessment and Prediction Program (MARMAP) at MRRI since 1979 to assess the status of reef fish stocks. Catch per unit of effort (CPUE) statistics are calculated on species of commercial importance, and results are reported annually to management agencies. Trends of decreasing mean length along with decreasing abundance as indicated by MARMAP CPUE suggest that vermilion snapper and black sea bass are overfished and red porgy may be in a state of collapse.

Similarity in trends between CPUE and abundance of black sea bass and red porgy determined by Virtual Population Analyses (VPA) demonstrates that MARMAP fishery-independent data are a reliable indicator of relative fish abundance.

MARMAP life-history studies are conducted on fishes sampled during the annual survey, and are documenting changes in growth rates, size at age, and size at maturity, thereby corroborating overfishing of red porgy and vermilion snapper. In addition to samples obtained from the MARMAP survey for life history and other studies, project personnel conduct sampling at ports where reef fish are landed. Port sampling is useful for providing data on age, growth, reproduction and stock identification, and could be improved if fish were landed intact (ungutted).

Additional monitoring and assessment efforts in the near future will include developing pre-recruit indices of abundance for gag grouper in the SAB, by sampling juveniles in estuarine nursery habitats.

Summary of Group Discussion

Reef Fish Monitoring and Assessment at the Marine Resources Research Institute

The Marine Resources Research Institute (MRRI) is a cooperative effort of South Carolina and fisheries (sport and commercial), so it has a relatively large budget and good research vessels. It is involved in a MarMap, SeaMap project. MarMap has collected annual independent fish samples since 1963, using a variety of techniques, including removal sampling, hook and line, snapper traps and cameras triggered to photograph bottom areas — to pan the circle and get size estimates.

The red porgy has declined in mean length and there has been a decline in catch per unit effort (CPUE), a figure that can be correlated with the fisheries estimate of virtual population. The management options are pursued in tandem with the sampling. So far, the program has resulted in 14 permanently closed areas, although the fisheries will complain that not enough data are available to show that reserves work. Some people believe that many small areas are better than one large restricted area as dispersal does not seem to be a problem. Divers turn in fishers, and sometimes, fishers turn in each other; it can even be hard for scientists to get permits for working in the restricted areas.

Fish preserves attract tourists. Glover's Reef, off Belize, used volunteers and took port samples — analyzed ovaries, gonads, tissue samples, mucous for hormone assays, DNA. One question is do fish in reserves provide recruits to nonprotected areas. MRRI is working to get this information from DNA samples and from fish tagging studies.

Common (or is it Uncommon?) Sense about Coral Reef Monitoring

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Overview

The design of an effective monitoring program for coral reefs requires the careful consideration of a number of factors.

- What is the objective of monitoring? What level of change must be detectable to meet the objectives?
- How will the data be used?
- Who will do the monitoring (what is their level of expertise)?
- What methods will meet the objectives and be realistic, given the available time, money, equipment, and people? Which methods will work best at the chosen study site?
- For how long should data be collected?
- How frequently should monitoring be done?
- Is standardization of methods desirable or essential?
- How will the data be analyzed and interpreted?
- How will the data be stored and retrieved?

A number of reef monitoring manuals are now available, with methods ranging from fairly expensive and sophisticated to low cost and "low tech." In designing a coral reef monitoring program, some compromises will have to be made between the accuracy and completeness of the data, and the time, difficulty, and expense of collecting the data. Fortunately, relatively simple and inexpensive methods have proven to be extremely useful for monitoring purposes, in some cases providing information which is superior to that obtained from more difficult and more costly methods. For the purpose of this presentation I have drawn heavily on the National Park Service "Coral Reef Monitoring Manual for the Caribbean and Western Atlantic" which my research team published in June 1994.

Objectives

To a great degree, the objectives of a monitoring program will determine the most effective approach. The purpose may be to 1) evaluate the success of a particular management action (e.g., the establishment of a marine reserve), 2) to quantify the change in abundances of certain reef organisms, e.g. near a sewage outfall or dredging project; or 3) to detect natural rates of change in coral cover on a relatively undisturbed reef. In most cases, the goal is to detect or document change in the structure and (less frequently) the function of the reef. The level of change that must be detected to meet monitoring objectives will partially determine the approach which must be taken, in particular the precision that is required. Selection of methods will depend not only on what you are measuring but on the intended use of the data. Will the data be used for regulatory purposes or presented in a court of law in an effort to recover damages?

Long-term Monitoring vs. "Quick and Dirty" Assessments

Because changes in a coral reef may be almost imperceptible over the short term or highly variable from one year to the next, looking at the long-term trends in the condition of reefs is vitally important. Given the incredible variety in the structure of coral reefs worldwide, it's difficult (and risky) to depend on a single set of observations or on "indicators" when trying to evaluate reef conditions. For example, high coral species richness is not necessarily a sign of optimal reef conditions because many of the stresses which affect reefs result in decreases in abundances of organisms rather than loss of species. High densities of juvenile corals probably are one of the better indicators of the status of a reef. In general, the best approach is to look for relative changes in a particular reef <u>over</u> <u>time</u> when trying to elucidate trends.

Repeated sampling at permanent sites over an extended period of time provides the most valuable data. The permanent sites should initially be selected haphazardly or most statistical tests will be invalid. Sites that are randomly selected each time are considered inherently less biased because the "representativeness" of permanent sites can always be questioned. However, sampling at different sites each time may not be sensitive enough to measure change because of patchiness in the reef. In addition, the use of temporary sites requires more samples to give the same level of statistical confidence as provided by repeat sampling at permanent sites. Permanent sites are generally recommended for long-term monitoring because they offer the greatest amount of information, consistency, repeatability and reliability.

Recommendations on Methodology

No single set (or type) of measurements will be ideal or even workable for all locations or at all times, and the methodology must be flexible in order to avoid over or under-sampling. Monitoring is a dynamic process, one which may need to be altered in response to substantial changes that occur over time. For example, changes in coral cover can be adequately measured with much less sampling effort when cover is uniformly high than when it is low and patchy. Changes in the number of samples or sampling frequency, or a shift to a different technique, should only be done after careful analysis to ensure comparability of data collected over time.

Because no one data-gathering technique is likely to provide all the information that will be useful, it's best to use a combination of photographic and non-photographic methods, if possible. In many cases, the objective will be to document changes in percent cover and the spatial arrangement of stony corals, because they create the structure of the reef.

Quadrats, photo-quadrats, and chain transects are alternative techniques for measuring percent cover, species diversity and relative abundance. Each method has its advantages and limitations (Table 1). Ideally, a coral reef monitoring program will include more than one method.

Photography should be a major component of any reef monitoring program. Photographs and videotapes are essential to any attempt to document changes in reef structure, and, unlike any other method, provide a visual record of reef conditions which can be analyzed when time permits. However, some photographic methods (specifically, computer-assisted image processing of videotapes) have not lived up to expectations.

Most monitoring programs are designed to examine changes in reef structure. In many cases, physical and chemical properties of the water should be measured regularly for possible correlation with any changes observed on the reef. In addition, monitoring of ecological and structural components of a reef should be supplemented with collection of information on human activities such as snorkeling, boating, fishing and diving when these activities are suspected causes of reef degradation.

It is important to keep in mind that long-term monitoring may show a correlation, for example, between reef conditions and certain environmental parameters such as increased temperature, but monitoring must be supplemented by experimental research to determine cause and effect relationships.

Frequency of Sampling

Sampling should be done often enough to obtain documentation of changes in reef organisms of interest, but not so frequently that it is destructive or inefficient. Monthly observations are generally best for monitoring individual coral colonies. Quadrat and transect surveys done every 6 months provide sufficient data for assessing changes in percent cover and species diversity, and reduce the risk of damaging reef organisms during the survey process. Of course, in the event of a storm, oil spill or other disturbance, it's important to assess the effects as soon as possible, survey permanent quadrats or transects from which

Table 1. Comparison of Monitoring Methods

	Quadrats	Photo-Quadrats	Chain Transects
Equipment	Relatively inexpensive	May be very expensive, depending on equipment used	Relatively inexpensive
Difficulty	Relatively simple, but at least for initial survey must be done by someone who can identify species in the field	May be difficult to set up depending on equipment used, but simplest methods can be done by non-specialists	Tedious and exacting; must be done by specially trained divers
Damage to reef	Slight risk in areas of high relief, especially if grid is used	Depending on equipment used, may be risky in topo-graphically complex areas	Even well-trained divers find it difficult to avoid causing some damage, especially in areas with branching corals
Data obtained	If grid is used, can provide reasonably accurate mea-sures of percent cover, species diversity, relative abundance, density and size	Can be used to estimate percent cover, species diversity, relative abundance, density and size	Measures all surface areas below line to determine percent cover, species diversity and relative abundance; estimates spatial index
Limitations	Cannot be used to measure spatial relief; provides data only on projected surface area; difficult in elkhorn or staghorn-dominated areas	Cannot be used to measure spatial relief; provides data only on projected surface area; unsuited to areas with large or abundant octocorals that conceal other species	Cannot be used to directly mea-sure species density or colony size; not suited to areas where stony corals are widely-spaced and small; impossible in elkhorn or staghorn-dominated areas
Use of data	Data are ready to use when diver leaves the water	Measurements cannot be determined until after photo-graphs have been digitized	Data are ready to use when diver leaves the water
Replication of survey	Relatively easy, if done by the same person each time or by people who have been trained together	In permanent photo-quadrats, precision depends on appa-ratus used and ability to take photo from exactly same spot	Even with well-marked transect, impossible to position the chain exactly the same each time
Calculating percent cover	Can be easily calculated, manually if necessary	Digitizing is time-consuming to do manually and difficult without access to computer and software; use of random dots also time-consuming	Can be easily calculated, manually if necessary

data were obtained before the disturbance, and continue to monitor the aftermath and recovery.

Sample Size

A pilot study can also help determine the most effective sample size for obtaining the required information. For example, the optimal sample size can be calculated by plotting sample effort versus the number of species seen during your pilot study. If an appropriate method is selected, but the sample size is inadequate, the credibility of any conclusions drawn from the data are irreparably compromised.

Quality of the Data/Collection and Handling (QA/QC)

The following procedures are recommended to; ensure the highest quality of data collection: peer review of sampling design (with assistance from statisticians), initial pilot studies to determine suitability of selected methods,well-written protocol/method descriptions, standardized field sheets, random checking of data sheets for verification, careful calibration of all equipment, and prompt entry of field data into the computer.

It is important to compare the results of repeated sampling. Sampling should be repeated within a short time interval, preferably by different observers, to assess the variation inherent in each method. Only when monitored values differ by more than the "method variance" has a real (statistically significant) change been detected. The variability between data collectors should be checked by having them record data for the same sample (for example, a quadrat) and comparing the results.

Standardization of Regional and Global Data Collection Efforts

A regional or global overview of coral reef conditions depends on some level of standardization of data collection efforts at representative sites. Unfortunately, it will simply not be possible to use exactly the same techniques at all sites. Anyone who doubts this should spend one day diving in Palau and one day in Jamaica. The structural characteristics of the study reef will in some cases preclude the use of certain methods. Reefs that are especially patchy, with high relief areas dispersed over sparsely covered areas, will present challenges, as will sites which are exceptionally diverse. Every effort should be made to standardize monitoring methods; when this is not feasible, it will still be possible to make some valid comparisons if monitoring has been conducted rigorously and in a statistically defensible way.

Use of Volunteers

It is not possible to use trained reef scientists in every location where data are needed, and volunteers have made and will continue to make significant contributions to a number of monitoring programs. However, not all volunteers are created equal. Sometimes you get more than you pay for, sometimes you get less! It is my opinion that many people continue to underestimate the difficulty of getting high quality data on reef conditions. Effective use of volunteers requires very careful design of the monitoring program by experienced reef scientists and hands-on training in the field and in the laboratory. Volunteers with very limited scientific background may be very careful and conscientious, but they are likely to make the wrong "on the spot" decisions should any problems arise in the data collection. Methods designed to examine changes in reef function (productivity, coral growth) are typically more difficult to do than methods to examine changes in reef structure and less appropriate for volunteers. Photographic methods are particularly effective if volunteers are doing the monitoring.

Summary of Group Discussion

Common (or Is It Uncommon) Sense about Coral Reef Monitoring

The challenge involved in designing a global monitoring network depends on several variables:

- one's management objectives — or how the data will be used —
- who will monitor,
- using what methods,
- when, how long, and how frequently,
- and how will the data be analyzed, stored and retrieved.

Only then can we decide whether low tech methods can be sufficient for our purposes. We will probably need a variety of methods and long-term monitoring at randomly selected permanent sites to document changes in structure or function of the reef and trends over time. Clearly, however, we have made progress since the early days of top-heavy diving equipment and the dynamiting of reefs. The National Biological Service (the National Park Service, Virgin Islands National Park) has prepared a coral reef manual for the U.S. Virgin Islands: *Coral Reef Monitoring Manual for the Caribbean and Western Atlantic*. It is, like many other manuals immensely helpful, but manuals must be backed up with technical assistance and explanation.

Volunteers may be used for communications programs as well as for diving. Simultaneously, however, we must be careful not to underestimate the resource managers in the developing countries — the Conservancy and others are providing improved training, and expertise may run higher than we know. A combination of methods is necessary — quantitative data must be collected and we must have more statistical rigor; however, qualitative information is also important, and can often be compelling.

At least 25 percent of our budgets must be for handling data. We have to be certain that it is collected in a uniform manner so as to be available to other people — especially if our objective includes long-term monitoring over time. What level of change is detectable and sufficient for our interests? If we are collecting indicator species, indicators of what? For example, coral species may be present but threatened, so perhaps the number of juvenile corals in the population would be a better indicator — a good sign that the species is healthy.

We also need to monitor what human beings are doing: number of dives and divers, boats anchored on the reef, fishing, etc.

Monitoring should be supplemented with cause/effect research. We really need pilot studies, so that we are not just "armchairing" the data. Quality assurance and control must be a part of all studies. These controls can be painful to contemplate but they result in improved studies. Standardized spread and field sheets are needed; so are careful calibration of all equipment, peer reviews, and resampling efforts to eliminate observer bias.

Volunteers and even biologists need a fair amount of training and experience. The Park Service uses the "Coral Reef Assessment Process" — which does not yield a suitable acronym as you can see. We also need reference sites. The reef hit by hurricane Hugo experienced a 40 percent drop in productivity, and has not yet rebounded — is it slowly recovering or not? To know for sure, we need reference sites. What are the controls on reference sites?

How we define a healthy reef is also critical to the methodology. Obviously we are putting human values here: what do we want here and what are we seeing here now? Scientists need to help build a shared vision that brings in the community. Reefs differ one from another, and some that are very different may actually be in good condition. How, then, do we know what to compare them to (we can't just go to Tobago or wherever)? And how do we translate our findings into management: what is happening? do we see trends developing? changes? how much is natural change? how much is human-induced? what is the norm from which we started? what influence can we have on the reef? We must be collecting management data.

Coral Reef Monitoring: A Caribbean View

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1. Assessment by What Criteria?

By what criteria are we "to assess the biota and habitat conditions of coral reefs." Reef resources include the provision of biodiversity, coastal protection, beach nourishment, recreation and food. Societies differ in the values they place on these resources: the last is important in the "third world." In the Caribbean, we think about the monitoring and management of coral reef **resources**, in the context of ICZM, and cannot take a purely preservationist view.

2. Comparison with What?

How do we assess (judge) the condition of coral reef resources? First, by comparison with other sites. Does it deviate from the norm for a pristine site "of the same habitat characteristics"? The last phrase is important: the world is complex and our understanding of habitat characteristics (oceanography, history and linkages to other systems) is often incomplete. Reefs which seem less "healthy" (a term I would like to discourage) are sometimes different for natural reasons. Nonetheless, parameters such as the abundance of macro-algae, the abundance of living corals, and the fish community composition, may indicate human disturbance. Sometimes there are no pristine sites left, and comparison must be with historical data or supposed general standards. It concerns me that (among other impacts), the *Diadema* mass mortality in the Caribbean was 12 years ago, and many young researchers now monitoring reefs did not know their less-disturbed state.

Secondly, one can compare resources at a given reef over time, to detect changes (some of which may be apparent at a first survey: an experienced eye can recognize signs of recent change which are not apparent from bare survey data). Of course, reef communities are dynamic, and they are going to change anyway. We know that there are seasonal changes, specific displacements and intermittent disturbances. There has not been enough long-term research for full familiarity with natural changes over the long-term. Replication is important. 10 independent m^2 quadrats are more statistically useful than one of 10 m^2.

3. Indicators

Miller & Hulbert (1994) point out that by the time coral abundance declines management action may be too late; early warning indicators of community stress and impending change would be valuable. In Jamaica in the 1970s, over-fishing was deduced, not only from the fish community but from the abundance of *Diadema* and damsel-fishes (Woodley, 1979). Over-abundance of green filamentous algae (such as *Chaetomorpha*) is an obvious indicator of excess nutrients.

4. CARICOMP

This is a network of 20 Marine Labs, Parks and Reserves, in 18 countries, established through UNESCO to measure Caribbean coastal marine productivity at comparable "pristine" sites, with identical methods, looking for regional patterns. But the fact of global change, and the prospect of more, has increased the importance of the monitoring program, and brought more funding for it. Nonetheless, fieldwork is (so far) funded entirely by the participant institutions, which has constrained the program to very basic measurements, known as Level 1. These were designed as a basis for measuring productivity: not for assessing change in (for instance) coral cover.

CARICOMP collects meteorological and aquatic physical data, measures biomass and productivity of mangroves and seagrasses, and records benthic community composition on coral reefs. There are 14 protocols, of which only 4 take place on coral reefs. These are weekly physical data and twice-yearly chain transects, plus belt transects for gorgonians and sea-urchins. Next, we shall introduce fish counts.

5. CARICOMP Experience Relevant to this Meeting

(a) *Methods Manual.* A Methods Manual has been written (in spanish and english), which is an explicit, unambiguous guide.

(b) *Physical data.* Temperature, salinity and secchi depth are collected manually, once a week. Now we have acquired cheap thermographs (HoboTemp, by Onset, < $100). Secchi readings are difficult and unreliable when made from a small boat with a sea running and the trade-winds blowing.

(c) *Benthic transects.* Cost considerations excluded photoquadrats or video for benthic monitoring. We chose chain transects because of the focus on productivity, and thus surface area, and the additional benefit of an index of rugosity (Rogers et al., 1982). We chose the intercept method, rather than points on the line, because of the additional information on colony sizes. Finally, we chose permanent transects, selected randomly, but re-visited for repeated measures, to eliminate the variability that would be introduced by successive random sampling. Masonry nails, every metre if possible, assist in accurate re-location of the chain. Supplementary belt transects record gorgonians and echinoids. Substratum Categories (eg Fleshy Algae, Massive Coral, Fan Gorgonian) are used, with genus or species identification optional.

(d) *Site selection.* The Program could afford only one set of reef transects at each CARICOMP station. The fore-reef at 10 ± 3m depth was selected, aiming for the Mixed Zone, the depth of which will vary with the prevailing wave energy. Choose, says the Manual, the "best" reef zone, where *Montastraea annularis* (sensu lato!) is probably abundant. Within that zone, two similar but separate areas were chosen, within each of which five permanent 10m transects were randomly established along contours. The performance of the ten 10m transects at each site is currently being evaluated.

(e) *Data entry.* To help eliminate errors in data entry or processing, we designed spreadsheet templates for each of the 14 sampling protocols. For reef transects, successive link numbers are entered, and 4-letter codes for substratum category, genus or species. The spreadsheet enters the intercept length and the full name of the taxon. We have not yet selected a database program.

6. Recommendations for Low-tech Monitoring

In many countries, there is an urgent need for large-scale assessment of the status of reef resources. For extensive cover, they need a quick method, but usually have very few staff. For that purpose (in developing countries, not necessarily in U.S. territories), I suggest transects swum by trained observers, who would make visual estimations of percent distribution of major substratum categories and visual fish counts. More detailed monitoring could be set up at a smaller number of permanent sites, perhaps with the assistance of Dive Operators, as shown by Smith (1994).

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Summary of Group Discussion

Coral Reef Monitoring: A Caribbean View

Coral Reef health is not the best metaphor to describe functioning natural systems. Health is a term used for people and corals; but once applied to reefs it is a metaphor that carries human value judgments. What we usually mean to describe when we use the term "unhealthy" is a reef that is changed — not for the better — by human uses. Chronic influences, such as terrestrial runoff of sediments, nutrients and pesticides, and overfishing, have contributed to the delay or slowing down of reef recovery from acute effects such as hurricanes. Thus, hurricanes have a larger and longer effect on reefs influenced by human uses than they would have in a "more natural system."

Assessment is the status or condition of a reef compared to a pristine site, either with itself over time or with a similar ideal site. What we want to do in monitoring the reef is measure changes. We do not yet know enough about natural changes, though we know that changes in the abundance of macroalgae, the number of living corals, and the fish communities may signify human stressors. Reefs may also differ for natural reasons that we may not always understand (e.g., coral communities on hard bottoms are different than corals in other naturally functioning systems).

History of the site is important. In the last few years a whole generation of divers, researchers, and volunteers have sprung up that may not know the condition of the reefs as they were just 20 or 30 years ago.

CARICOMP is a network of 20 marine labs monitoring reefs in the Caribbean. The labs collect meteorological and aquatic data. CARICOMP received new impetus during the decade of the 1980s with its emphasis on global change, but funding is almost entirely up to the cooperating institutions. The group must look at resources — the effect of fishing on the food supply, for example. That is, we cannot afford to take a preservationist view. Monitoring is done in the context of the International Coastal Zone Management (ICZM) agreement.

Monitoring is done using 14 different protocols on various time schedules: weekly, seasonally, biannually. We measure temperature, salinity, and secchi disk depth, among other things, weekly, using Hobotemps to make thermographs. Hobotemps, a device made by Onset, cost less than $100 each. We will add fish counts in the coming years.

We do not use photoquadrats or video for our benthic monitoring. But we use chain transects — with the intercept method rather than points on the line — to get data on colony sizes. We use permanent transects, frequently visited, and masonry nails placed every meter or so to help relocate the chain. The database is maintained at the University of the West Indies in Jamaica.

CARICOMP has its own manual — pretty much a cookbook approach. It has no cameras, however. The budgeting is pretty much based on the lowest common denominator. It is not low tech — probably not to be recommended to developing countries, yet its protocols are level one, which is all we can afford. Programs that have quite a long coast line use transects and intercepting transects to get plenty of replicates for many different places.

The first objective was to establish the environment's productivity; that goal is becoming overshadowed by the need to document changes. Though some members of the symposium thought adding camera work would be immediately valuable, they were reminded that photos have to be analyzed and archived — again the personnel for that would add "high tech" to the need for collecting data.

CONCLUSION AND NEXT STEPS

The importance of coral reef ecosystems may be seen in their numerous ecological, aesthetic, economic, and cultural functions. Atoll and barrier reef islanders recognize that healthy reefs are essential for the support, creation, and repair of the coral islands upon which they live. Coral reefs also protect coastlines from shoreline erosion, and serve as a living pantry for the subsistence harvest and consumption of many reef organisms. The cycle of reef accretion and erosion maintains beaches and provides habitat for seagrasses and mangroves.

Coral reefs are important recreational resources for many of the world's people, especially those having the privilege of living near them. In the modern era, coral reef passes and channels provide safe navigation channels for boats, and harbors are often sited on reefs because they provide natural protection from heavy wave action. Coral reefs are fast becoming the main attraction for visitors to many tropical island and coastal destinations. Coral reefs are also the favorite sites of many governments and developers, and reef rock is mined in many countries to provide armor stone and building materials. Few aspects of these activities, especially modern uses, are beneficial to reefs, and scientists and other reef users are beginning to realize that coral reefs are fragile and gravely threatened in many areas of the world by chronic anthropogenic reef disturbance. The ability of coral reef ecosystems to exist in balanced harmony with other naturally occurring physical, chemical, and biological agents has been severely challenged in the last several decades — mostly as a result of poorly managed anthropogenic activities.

Globally, scientists are now working together and with other groups to promote assessment, monitoring, and other research to protect and restore coral reefs. Establishment of coral reef initiatives at the local community, national, and regional levels are essential for long-term sustainable use and conservation of these critically important habitats. The focus of these initiatives should be to help culturally, economically, and politically diverse peoples around the world develop integrated coastal zone management programs with emphasis on local community involvement and leadership. Much potential exists for using volunteers (with the appropriate training) to significantly enhance current capabilities for long-term monitoring and assessment of coral reef ecosystems, especially in more remote regions.

The primary objective of the United States Coral Reef Initiative (U.S. CRI) is to foster innovative cross-disciplinary approaches to sustainable management and conservation of coral reef biodiversity and ecosystems through the development of cooperative relationships among the various stake-holders. Perhaps the most important element within the U.S. CRI is support for community involvement in developing and implementing local and regional CRIs suited to those community needs and situations. For United States and International CRIs to effectively conserve and manage coral reef ecosystems for long-term sustainable use, programs should rely essentially on local community involvement. Scientists, government managers, nongovernmental organizations, and other interested residents have been actively planning local coral reef initiatives throughout Hawaii, Guam, the Commonwealth of the Northern Mariana Islands, American Samoa, Florida, Puerto Rico and the U.S. Virgin Islands.

The purpose of this symposium was to review promising, practical, low cost/"low-tech" approaches for long-term monitoring, surveys, and assessment of coral reefs. The previous sections of this report describe a variety of different methods ranging from visually based methods that use diver observations and photographic records to establish temporal trends to the use of indicator species or water quality characterization. The discussions that followed each presentation, the breakout groups, and the final plenary discussion were very useful in setting a direction for the "next steps."

The question still remains as to whether and what kind of technical guidance document is needed to provide the basis for using biocriteria to assess the condition of coral reef habitats. The development of a coral reef biocriteria program should employ an iterative approach built on science and a partnership between federal, state, and local agencies. In providing technical guidance, the federal government (i.e., EPA) would be offering a methodology that state governments could then adapt to specific conditions in their region — a methodology that would enable them to set the criteria (with EPA involvement) to help determine how land uses, water quantity and quality, energy flow, habitat, and biota can be managed to protect and restore coral reef ecosystems. The EPA did not ask the participants of this symposium to help prepare criteria or standards but to help determine what technical guidance is needed to help states, territories, and commonwealths develop their own biological criteria and standards. The development of consistent biocriteria methods may be a research issue, but the ultimate criteria and standards are management concerns that must be addressed by the EPA, states, territories, and commonwealths. The symposium provided a good assessment of the state of coral reef monitoring technology. The next steps are to determine (a) whether sufficient need exists to prepare a guidance document of consistent standardized survey methods, (b) whether sufficient information exists to draft that guidance, and (c) what if any pilot projects are needed to support such an initiative.

In any case, a clear need exists for biological surveys of benthic, coral, and fish communities to collect the raw data that can be converted into some form of condition indices. Ideally these indices would be indicative of levels of stress or change before the "point of no return" so that appropriate research can be initiated to provide information to the management community responsible for mitigation strategies. There have been numerous calls (see previous sections of this report) for a network of "index" sites for long-term monitoring and assessment at the national, regional, and global levels. The current dearth of individuals with high level technical expertise, not to mention funding resources, precludes the implementation of such a comprehensive network of coral reef monitoring sites (especially in remote regions) without the significant involvement of adequately trained, local-level participants. Many nongovernmental groups have been at the forefront of various local coral reef monitoring efforts. These grassroots efforts should be applauded and encouraged. However, long-term national and globally coordinated coral reef monitoring programs are essential to manage, archive, translate, and transfer data to scientists, managers, and other interest groups. NOAA is developing a nationally coordinated coral reef monitoring program to be implemented in 1996 and actively pursuing partnership efforts with other agencies (such as the National Park Service and the Environmental Protection Agency) and volunteer interest groups (such as American Oceans, The Nature Conservancy, REEF, and Reefkeeper).

Since this symposium was held, a pilot project has been initiated to develop a training manual and video for initial assessment and long-term monitoring of coral reef ecosystems based on the transfer of noninvasive, "low-tech" approaches to volunteers. The Department of Defense, the U.S. Man and the Biosphere Program, NOAA, EPA, University of Hawaii coral reef scientists, and natural resource agencies in Hawaii, American Samoa, and the Commonwealth of the Northern Mariana Islands Coastal Zone support this project, and their collaborative interplay will produce information vital to the future planning and management of sensitive marine habitats and facilitate the transfer of developed techniques and information to local peoples in the American Flag Pacific Islands and other sites around the world. It will be especially valuable as a low cost, low technology method useful in areas of the world that critically need assistance to determine the level and degree of environmental perturbations to coral and hard-bottom marine habitats. The project will enhance partnerships in training and information transfer and empower local populations to better assess and manage their coral reef ecosystems. Its specific product will be a handbook on noninvasive and "low-tech" approaches to assessing and monitoring coral reef habitats. The handbook will serve as a reference for individuals with limited technical science background and expertise; its contents will include step-by-step instructions for determining the behavior of coral-feeding fish and for relating these traits to changes in coral habitat condition and the basic techniques for assessing coral and fish biodiversity and percent of cover. The video will explain the coral reef ecosystem and demonstrate coral reef monitoring and assessment instructional training.

This symposium, and the pilot projects described here can help EPA decide whether now is the time to draft coral reef biocriteria technical guidance. Each is a step in the direction that we need to go to "turn the tide" of the decline in coral reef habitat and condition in the years to come. The participants of this symposium have a great wealth of expertise, knowledge, and concern for the coral reef ecosystems of our nation and the world. They deserve our gratitude and our continued encouragement and support as we seek to turn that tide and provide future generations the opportunity to enjoy coral reefs and to develop sustainable uses for these remarkably valuable and beautiful ecosystems.